THE INFLUENCE OF SMOKING ON DISABILITY FOLLOWING HOSPITALIZATION FOR MUSCULOSKELETAL DISORDERS

by

Andrew E. Lincoln

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ABSTRACT

Statement of the Problem:

Musculoskeletal disorders are a primary source of morbidity, lost time, and lost readiness in the military. The combined categories of injuries and musculoskeletal/ connective tissue disorders account for the largest proportion of hospitalizations in the U.S. Army (30%) and the leading cause (51%) of diagnoses resulting in discharge from the service because of disability. Despite the high incidence of these disorders and the tremendous lifetime costs associated with permanent disability (an average of $277,000 per case), little is known about their natural history and long-term outcomes, the likelihood that they will result in permanent disability necessitating medical discharge, or those factors associated with an increased likelihood of disability.

Purpose:

The purpose of this research was to investigate risk factors for the development of physical disability following the incidence of a musculoskeletal disorder. The natural history of various diagnostic categories was described from the point of initial hospitalization to the outcome of medical discharge from the service for disability. In addition, potential risk factors that may contribute to this outcome were studied. In particular, the role of smoking was investigated among each of the diagnostic categories to determine whether there was variation in smoking's effect and which diagnoses were more susceptible to those effects.

Methods:

This retrospective cohort study made use of four types of data: demographics, health behavior and practices, health outcomes (hospitalizations), and functional outcomes (disability ratings). Five separate databases containing these data were linked: personnel, hospitalization, health risk appraisal, disability, and loss from service. Data were obtained from the Total Army Injury and Health Outcomes Database (TAIHOD), a collection of databases that was recently created primarily for injury prevention and women's health research. Unique identifiers (scrambled social security numbers) enabled the linkage of information across databases, in effect permitting me to track the natural history of a subject's condition. This study assessed the roles of demographic, behavioral, psychosocial, occupational, and clinical characteristics in the development of physical disability. Subjects included 15,268 U.S. Army personnel hospitalized for a common musculoskeletal condition between the years 1989-1996 who had completed a health risk appraisal and were followed through 1997. The cohort did not include persons hospitalized for all musculoskeletal conditions or injuries, but only those with certain well-defined diagnostic categories. Survival analyses involved Kaplan-Meier estimates of cumulative survival, log-rank tests for equality and trend, and Cox proportional hazards models.

Results:

The initial review of the literature (presented in this dissertation as a review paper) identified smoking to be a significant risk factor for low-back pain (OR knee condition, having a high school education was the greatest risk factor for developing disability relative to those with college degrees (relative hazard = 8.8, 95% confidence interval: 2.7, 28.7). Factors not significantly associated with the development of disability were race/ethnicity, marital status, number of dependents, alcohol use, body mass index, and health practices index. Also, terms that addressed the potential interaction of cigarette smoking, alcohol use, work stress, job satisfaction, age group, and length of service were found not to be statistically significant.

Findings from the second set of analyses indicated an association between smoking level and disability discharge when all musculoskeletal categories were combined. Kaplan-Meier estimates illustrated distinct survival curves among different smoking levels and log-rank tests demonstrated dose-response associations between increased smoking level and cumulative risk for disability discharge for all knee disorders (e.g., meniscal injury ($p<0.001$), cruciate ligament injury ($p=0.08$), collateral ligament injury ($p=0.003$), and chondromalacia ($p=0.03$)), rotator cuff injury ($p=0.01$), and intervertebral disc displacement ($p=0.05$). However, when adjusting for stronger predictors in multivariate Cox proportional hazards models such as age group, sex, and length of service, smoking was significantly associated with only meniscal injuries (light smokers had a 44% greater risk than nonsmokers and heavy smokers had a 49% greater risk) and all musculoskeletal categories combined (heavy smokers had a 21% greater risk). Smoking was also associated with disability among persons with carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, and chondromalacia, although not at statistically significant levels.

Former smokers appear to be protected for all musculoskeletal categories combined, though not significantly (RH=0.94, 95% CI: 0.80, 1.11). Overall, the attributable risk of disability due to smoking among current smokers and nonsmokers was 18%, while among current smokers with meniscal injuries, 38% of disability discharges were attributable to smoking.

Conclusion:

The review of the literature provides a sound biological basis for smoking to affect tissue blood supply and other factors affecting the healing process and, consequently, the likelihood of progression to disability. The meniscus is particularly likely to be affected as it has limited vascularization that penetrates only its peripheral 10-25%. Thus, smoking's effect of reducing blood flow may further limit the supply of nutrients to the damaged tissue.

This study successfully demonstrated that it is possible to link large existing administrative databases for the epidemiological study of injury and disability and provides a useful model for future studies. This population-based, retrospective cohort study strongly suggests an association between smoking and the development of disability for meniscal injuries based on multivariate analysis and a high attributable risk. The findings also suggest that a smoking cessation intervention among Army personnel who injure their menisci may serve as an important means to prevent the development of disability, especially since the effect seems to be reversible as former smokers have risks similar to nonsmokers.

Although smoking was found to be the single significant behavioral predictor of disability, smoking cessation is particularly difficult to achieve in the military. Prevention and cessation efforts must overcome a long history of condoning and even encouraging smoking, the popular image of macho soldiers with cigarettes, and the tendency for personnel to initiate or resume smoking in order to assert their individuality or relieve stress. However, the recent development of tailored intervention programs for military personnel and the involvement of physicians trained in smoking cessation counseling may offer an additional mechanism to reduce the development of disability and the many other ill effects associated with smoking.

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Anyone who has had the opportunity to write a section such as this is very fortunate, indeed. I am no exception. The completion of this dissertation is the reflection of lots of work, motivation, support, and faith.

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I can honestly say that the experience of the doctoral program and even the dissertation writing has been very rewarding and even enjoyable (except for the occasional attack of self-doubt). Along the way, I benefitted from the wisdom of many faculty: Susan Baker, for her keen insight; Jackie Agnew, who suggested it was about time I get the dissertation done when I presented her with my third dissertation proposal; Cliff Mitchell, for keeping my ideas relevant and grounded with the "So what?" question; Mei-Cheng Wang, who presented survival analysis as a user-friendly concept and gave me confidence in my analytic skills; and Ellen MacKenzie, who suggested the final research topic after my second proposal had been quashed.

This work would never have occurred if not for the belief and support of LTC

Paul Amoroso at the U.S. Army Institute for Environmental Medicine. Paul invested a sizeable degree of support in this effort and I am very grateful for his confidence in me and interest in this work,. I thank the program analyst, Michelle Yore, for her skill and months of work, without which I would still be writing program code at this time. The success of this study is largely due to her skills.

As motivation and support go, I share this accomplishment with my family - Lisa, Jessica, and Noah. Lisa always provided me with the love, confidence in my abilities, and gentle reminder of where my priorities were. Jessica (my "Big Girl") offered a wonderful distraction from regression models and literature searches and always lifted my spirits. Noah, now only one month old, gave me the "motivation" to get this done as soon as possible. I look forward to sharing this thing called "weekends" with each of you now. I will always be most proud of my family.

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CHAPTER 1. LITERATURE REVIEW

The Association Between Musculoskeletal Disorders, Disability, and Smoking: A Review of the Literature

Andrew E. Lincoln, MS [1]
Gordon S. Smith, MB, ChB, MPH [1]
Paul J. Amoroso, MD, MPH [2]
Richard Hinton, MD, MPH, MPT, MEd [3]

[1] Center for Injury Research and Policy, Department of Health Policy and Management The Johns Hopkins University School of Public Health, Baltimore, MD

[2] U.S. Army Research Institute of Environmental Medicine, Natick, MA

[3] Department of Orthopaedic Surgery, The Union Memorial Hospital, Baltimore, MD

Address for correspondence and reprint requests:
Andrew E. Lincoln, M.S.
The Johns Hopkins Center for Injury Research and Policy
624 N. Broadway
Baltimore, MD 21205
(410)614-4023, fax (410)614-2797
alincoln@jhsph.edu

2 Tables, 1 Figure

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Abstract

Despite the high incidence and costs of musculoskeletal disorders, little is known regarding those factors associated with an increased likelihood of disability. Smoking is one important and often overlooked risk factor that has been suggested to influence the incidence of musculoskeletal disorders and injuries. We examined the epidemiologic evidence relating tobacco use to the incidence of acute injuries or musculoskeletal disorders and their healing and found smoking to be a significant risk factor for low-back pain (OR ranging from 1.2-3.0), lower extremity injury (1.9), carpal tunnel syndrome (1.6), and fracture/non-union (4.1-7.9). In addition, potential physiological and psychosocial mechanisms are assessed and explanations were found to suggest how tobacco could also influence the risk of subsequently developing a physical disability. We propose a multifactoral model that illustrates the factors that influence the transition from musculoskeletal disorder to physical disability. A better understanding of potential predictors of disability, such as tobacco use, will be necessary to identify potential interventions and minimize the long-term sequelae associated with musculoskeletal disorders.

Introduction

Musculoskeletal disorders are a major source of morbidity, lost time, disability, and cost in the modern workforce. Recent statistics from the Bureau of Labor Statistics indicate that disorders associated with repeated trauma accounted for 4 percent of the 6.2 million workplace injuries and illnesses in 1996, while sprains/strains represented 43 percent of non-fatal injuries and illnesses in 1995 (BLS, 1997a; 1997b). Not only do musculoskeletal disorders constitute the largest proportion of occupational injuries and illnesses, but carpal tunnel syndrome is also associated with the highest median number of days away from work (30 days) of all disabling conditions (BLS, 1997b). Carpal tunnel syndrome is but one of many musculoskeletal conditions that contributed to 315 million office visits and a cost of $149.4 billion in 1992 (Yelin and Callahan, 1995).

As defined in this review, musculoskeletal disorders (e.g., carpal tunnel syndrome, low-back pain) represent soft tissue conditions typically associated with repeated trauma and/or other ergonomic risk factors as well as injuries resulting from overexertion (e.g., sprains/strains). Because many of the recent findings that associate smoking with injuries and musculoskeletal disorders have involved military populations, much of the review will concentrate on these results. Although these findings may not always be entirely generalizable to the civilian workforce, they provide the best evidence we have and most results are just as likely to apply to the civilian workforce.

In a young, active population such as the U.S. Army, musculoskeletal disorders are the leading cause of hospitalizations (unrelated to pregnancy) among both women (247/10,000 person-years) and men (204/10,000 person-years) (Amoroso et al., 1998a). The rate is four times that of the U.S. civilian population (63/10,000 for women and 53/10,000 for men) (Graves and Gillum, 1996). However, the increasing treatment of these conditions as outpatient day surgery may mask their true magnitude in the civilian population whereas, in the military, same day surgery was still counted in their hospitalization database through 1995. In analyses of discharges from the Army for physical disability from 1990 to 1994, 59% and 67% of women and men, respectively, had musculoskeletal-related diagnoses (ICD-9-CM codes 710-739) (Amoroso et al., 1997). The annual cost of new disability cases in the Army is estimated to be nearly one half billion dollars and the Veterans Administration pays over 400 million dollars per month to veterans with permanent musculoskeletal-related disabilities (Jones and Hanson, 1996). A recent study of German construction workers found musculoskeletal disorders to be responsible for the largest proportion (40%) of early retirement due to permanent disability (Rothenbacher et al., 1998). Despite the high incidence and cost of these conditions, little is known about their natural history and long-term outcomes, the likelihood that they will result in permanent disability necessitating medical discharge, or those factors associated with an increased likelihood of disability.

Recent investigations of military and working populations have identified tobacco use as an independent risk factor for both acute injury and overuse musculoskeletal disorders (Kwiatkowski et al., 1996; Nathan et al., 1996; Reynolds et al., 1996; Dettori et al., 1996; Reynolds et al., 1994; Jones et al., 1993; Ryan et al., 1992; Tsai et al., 1992). It is hypothesized that characteristics of individuals, their behavior, occupation, and medical diagnosis can be modeled to predict the transition from an "injured" status to a "disabled" status. This conceptualization builds on an earlier multifactoral model relating tobacco and an elevated risk of acute injuries and musculoskeletal disorders (Amoroso et al., 1996c).

Although the health hazards of smoking are well-documented (DHHS, 1989), most health conditions resulting from smoking have a long latency. Specific exceptions to these long-term outcomes may include acute injuries and musculoskeletal disorders. In addition, the evidence of tobacco's effect on acute healing (Silverstein, 1992) and the (as yet) unrecognized role of tobacco in the development of disability may play a significant role in the medical and behavioral management of a musculoskeletal disorder. While tobacco use is typically eliminated during cardiac, stroke, and other types of rehabilitation, it is not yet considered as a risk factor for unsuccessful rehabilitation following the incidence of a musculoskeletal disorder.

The purpose of this paper is to: 1) review the risk factors for musculoskeletal disorders and disability; 2) examine the epidemiologic evidence relating tobacco use to acute injuries, musculoskeletal disorders, and healing; 3) discuss potential mechanisms of tobacco's influence on the incidence and healing of musculoskeletal disorders; and 4) propose a multifactoral model to demonstrate the transition from musculoskeletal disorder to physical disability.

A. Musculoskeletal disorders and risk factors for disability

Although risk factors for the incidence of musculoskeletal disorders are numerous and varied (Burdorf et al., 1997; Bigos et al., 1992), known risk factors for disability resulting from them are fewer and more specific. Risk factors identified by epidemiological studies include variables related to demographics, medical status, physical capabilities, workplace demands, and psychological/behavioral resources (Feuerstein, 1991). "Disability" is defined in various ways by different studies: disability discharge from military service (Berkowitz and Feuerstein, in press; Feuerstein et al., 1997); intense pain 2 weeks, 3 months, 6 months, or 12 months after injury, outpatient consultation, or hospital discharge (Deyo and Tsui-Wu, 1987; Lehmann et al., 1993; Burton and Tillotson, 1991; Hasenbring et al., 1994); did not return to work within 3, 6, 9, or 12 months following injury (Hazard et al., 1996; MacKenzie et al., 1997; Lancourt and Kettelhut, 1992; Volinn et al., 1991; MacKenzie et al., 1987); or measures of health status (e.g., Quality of Well Being Index), interference with activities of daily living (e.g., Sickness Impact Profile) and use of medical services 3 or 6 months after outpatient consultation or pain onset (Deyo and Diehl, 1988; Williams et al., 1998). Perhaps the World Health Organization's definition best represents the concept of disability as intended in this review, which denotes limitations of activities, abilities, or function (WHO, 1997).

The most consistent musculoskeletal-related risk factor for developing disability is increasing age (Berkowitz and Feuerstein, in press; MacKenzie et al., 1997; Badley and Ibanez, 1994; Cheadle et al., 1994; Hubert et al., 1993; Volinn et al., 1991). Cheadle et al. suggest two hypotheses to support this finding: older workers are less able to recover from injuries and are less able to find employment following recovery than are younger workers. Although Badley and Ibanez identified increasing age to be associated with musculoskeletal disability overall, persons with back-related conditions had the highest prevalence of disability in the 45-54 year age group, suggesting a different disability profile associated with low back injuries (1994).

Another consistent risk factor for musculoskeletal-related disability is female gender (Feuerstein et al., 1996; Cheadle et al., 1994; Hubert et al., 1993). Feuerstein's findings that women had higher overall and occupation-specific disability rates in the U.S. Army indicate that women may be affected by physical and psychosocial stressors in different ways than men. In particular, women may be affected to a greater extent because of "gender role or gender conflict in occupational settings, family and parental responsibilities, lack of adequate and affordable child care, sexual discrimination or harassment, and shift work" (IOM, 1995). Although Badley and Ibanez did not find sex to be a significant predictor of musculoskeletal disorder disability overall, they identified significant effects when examining arthritis disability (higher risk among women) and back disability (higher risk for men) separately (1994).

Being not married or divorced has been found to be associated with disability in a variety of studies (Hubert and Fries, 1994; Cheadle et al., 1994; Badley and Ibanez, 1994; Lehmann et al., 1993; Volinn et al., 1991). This finding may be strongly related to reduced social support, an independent risk factor identified by Berkowitz and Feuerstein (in press) and MacKenzie et al. (1987), and a greater incentive to provide for dependents among married workers.

Having less education has also been associated with a greater likelihood of disability (Deyo and Tsui-Wu, 1987; Deyo and Diehl, 1988; MacKenzie et al., 1997; Badley and Ibanez, 1994; Makela et al., 1993; Hubert et al., 1993). Deyo and Tsui-Wu suggested that men with little education and low-paying jobs would be more likely to perform heavy and physically stressful labor, which might also require a longer return to work than for those with sedentary jobs (1987). The authors offer other potential explanations, including the concepts that education may alter the attraction and motivation to perform one's job and that education may provide a better understanding of health risks, health behaviors, and more appropriate use of medical care. In short, a condition's effect on a less educated person may be more severe than for a person with greater intellectual resources (Makela et al., 1993).

Other indicators of lower socioeconomic status have shown a relationship to disability (Volinn et al., 1991; MacKenzie et al., 1987; Badley and Ibanez, 1994) as have aggregate-level variables such as higher county unemployment rates (Cheadle et al., 1994). Badley and Ibanez suggest one mechanism in the association between disability and lower income may be "downward drift": having to either leave the workforce or accept less demanding and lower paid work as a result of physical impairment.

Disability increases with a low or very high body mass index (Makela et al., 1993; Rissanen et al., 1990) and with less physical activity compared to one's peers (Hubert and Fries, 1994), participation in nonrecreational activities (Hubert et al.; 1993) or aerobic exercise (Berkowitz and Feuerstein, in press), suggesting that a more sedentary lifestyle may inhibit a successful recovery. Paradoxically, a history of physically strenuous work (Cheadle et al., 1994; Makela et al., 1993) has a higher risk of disability while having a white collar job that is not physically demanding (MacKenzie et al., 1997) is protective. These findings suggest that having a physically demanding job may 1) not afford the worker the necessary time to heal, and 2) reduce the likelihood of return to work for relatively minor disabilities.

Specific musculoskeletal diagnoses (e.g., carpal tunnel syndrome, back or neck sprain, inflammatory arthritis) have demonstrated elevated risk for long-term disability (Cheadle et al., 1994; Makela et al., 1993). Extended disability among a working-age population with overuse conditions, beyond that for commonly recognized severe and acute injuries (e.g., hernia, amputation), lends legitimacy to the long-term sequelae that chronic and overexertion conditions may present.

Lastly, results from several studies indicate that an employee's perceptions of the workplace (Williams et al., 1998; Berkowitz and Feuerstein, in press; Bigos et al., 1992; Lancourt and Kettelhut, 1992), distress (Bigos et al., 1992), coping mechanisms (Lancourt and Kettelhut, 1992; Habeck et al., 1991), and employer resources (Drury, 1991) may affect the likelihood of disability. For example, workers dissatisfied with their job tasks are at significantly higher risk for back injury (Bigos et al., 1992), extended absenteeism (Coste et al., 1994), and higher risk for disability (Williams et al., 1998). In their cohort experiencing first-episode back pain, Williams et al. found baseline job satisfaction to be predictive of pain, disability, and psychological distress at six months after pain onset. The investigators suggest that job satisfaction may offer an incentive to continue working while protecting against physical deconditioning and pain preoccupation. Also, Berkowitz and Feuerstein identified higher work stress as an independent risk factor for back-related disability in the U.S. Army (in press). From the employers' perspective, the resources available to a company may determine a number of aspects that may influence the ability for injured workers to return to work (Drury, 1991). For example, larger firms may have access to disability management specialists and have the flexibility to re-assign job tasks, modify work schedules, provide ergonomic accommodations, or offer light duty assignments.

All of these risk factors begin to sketch a picture of the injured person at elevated risk for progressing to a state of disability. However, few modifiable risk factors, such as smoking, have been evaluated. The following section presents evidence that smoking is a primary risk factor for acute injury, musculoskeletal disorders, and impaired healing.

B. Epidemiologic evidence of smoking's effect on acute injuries, musculoskeletal disorders, and healing

Despite obvious differences in the nature of acute trauma and chronic musculoskeletal disorders, some of the mechanisms that have been hypothesized to associate smoking and acute trauma may apply to musculoskeletal disorders as well. Tobacco use has been found to be an independent risk factor in many investigations of both acute injuries (Sacks and Nelson, 1994) and chronic musculoskeletal disorders (Bernard, 1997). Kwiatkowski et al. recently offered a detailed account of cigarette smoking's orthopedic-related effects and the associated biological mechanisms (1996). Table 1 presents a comprehensive summary of 40 studies that have used multivariate techniques to investigate the epidemiologic effect of smoking on musculoskeletal disorders or acute injuries. The studies are selected from an extensive annotated bibliography (Amoroso et al., 1996c), a doctoral dissertation (White, 1995), and Medline searches that identified articles published between 1976 and 1998 containing combinations of the following terms: smoking, tobacco use, injury, musculoskeletal disorder, and musculoskeletal disorder. Although the effect of smoking is positively and significantly associated with adverse health outcomes in most cases, studies that do not demonstrate an association for specific age and gender strata are included as well.

Insert Table 1 here

Low back pain, the most prevalent musculoskeletal disorder, has also been the most frequently studied for an association with tobacco use (Battié et al., 1989; Battié et al., 1991; Biering-Sørensen and Thomsen, 1986; Deyo and Bass, 1989; Frymoyer et al., 1980; Frymoyer et al., 1983; Heliövarra et al., 1991; O'Connor and Marlowe, 1993; Saraste and Hultman, 1987; Svensson et al., 1983). Most of these papers are occupational studies, which enables investigators to better assess exposures and control for confounding factors to a greater degree. However, studies in general have not controlled for the risks associated with smoking's effects, whether they be direct (e.g., physiological) or indirect (e.g., greater risk-taking behavior) (Sacks and Nelson, 1994).

The recent NIOSH review of epidemiologic evidence for work-related musculoskeletal disorders (Bernard, 1997) identified studies showing positive associations between smoking history and low back pain, sciatica, or intervertebral herniated disc (Finkelstein, 1995; Owen and Damron, 1984; Frymoyer et al., 1983; Svensson et al., 1983; Kelsey et al., 1984). Although some studies suggest an association between smoking and low back pain yet fail to achieve statistical significance (Boshuizen et al., 1993; Kelsey et al., 1980; Riihimaki et al., 1989; Hildebrandt, 1987), the most robust investigations all exhibit strong associations. For example, Battié et al. identified a 40% higher incidence of back pain among smokers (p=0.002) over a 4 year follow-up period (1989) in a rare prospective study of 3020 industrial workers.

Perhaps the risk factor of smoking for acute trauma is actually a chronic association, more related to person-time (e.g., pack-years) than the immediate physiological changes from smoking a single cigarette. Deyo and Bass (1989) found a dose-response relationship between prevalence of back pain and pack-years of smoking, a finding consistent with the results of Jones et al.(1993). One potential mechanism to explain this association is that back pain is caused or at least exacerbated by smoking-induced coughing, which increases abdominal and intradiscal pressures (Deyo and Bass, 1989; Troup et al., 1987; Frymoyer et al., 1980). Other possible mechanisms to explain tobacco's effect on weakening tissue include nicotine-induced diminished blood flow to intervertebral discs (Battié et al., 1991; Frymoyer et al., 1983) and reduced mineral content of bone resulting in greater susceptibility to microfractures (Svensson et al., 1983). Other smoking-induced effects have been suggested, including chronic vasoconstriction, tissue deoxygenation, and increased muscle tone (Knapik et al., 1997; White 1995). Such effects may make tissues more sensitive to physical stress, more vulnerable to injury, and less able to recover (White, 1995).

Recent studies have investigated the association between carpal tunnel syndrome and smoking. Tanaka et al. identified persons with a history of cigarette smoking to have an adjusted odds ratio of 1.64 (95% CI 1.03, 2.02) for "medically called" carpal tunnel syndrome in a national survey of the working population (1997). In a large survey comparing industrial workers with definite carpal tunnel syndrome to those without, Nathan et al. found a statistically significant 26 percent greater current use of tobacco and 19 percent greater lifetime use of tobacco among workers with a positive diagnosis (1996). In stepwise regression analysis, use of tobacco, alcohol, and caffeine were identified as independent predictors of definite carpal tunnel syndrome in female workers. Vessey et al. (1990) demonstrated significant associations between referral to hospital for carpal tunnel syndrome and age, smoking, oral contraceptive use, and body stature among women. Smoking provided the strongest association and evidence suggesting a dose-response effect with standardized rates tripling as smoking increased from zero to 25 or more cigarettes per day.

In regard to acute injury, Sacks and Nelson (1994) presented evidence of smokers' elevated risk in a variety of settings, including residential fires, motor vehicle crashes, occupational injuries, suicides, and other unintentional injuries. In Brison's study of motor vehicle crashes, smokers were found to have a 50% greater risk of crashing compared to non-smokers and a positive correlation between risk of crash and tendency to smoke while driving (1990). He suggested that these associations may be based on distraction from driving by the act of smoking, behavioral differences between the groups, and carbon monoxide toxicity. For example, it has long been recognized that persons who smoke are also more likely to use alcohol (Maletzky and Klotter, 1974). Carbon monoxide toxicity may affect the risk of a crash by impairing judgement and performance skills (Brison, 1990). White suggests an alternative mechanism of carbon monoxide may be evident, that of increasing muscle tone with chronic exposure (1995). In support of this hypothesis, White was able to demonstrate a positive association between increasing level of smoking and various musculoskeletal disorders in two of three investigations. These findings may be related to increased muscle tone resulting from carbon monoxide toxicity, but do not indicate whether carbon monoxide specifically is responsible or at what level of toxicity the mechanism may be activated.

In Amoroso et al.'s study (1996b) of acute injuries from parachute jumping, there was no association between injury and smoking status. Parachute injuries are associated with a single, high-energy collision in which potential mechanisms of injury are limited. In contrast, Reynolds et al.'s study (1996) of injuries incurred on a five day, 100-mile road march revealed that smokers had greater risks of injury (OR=1.93, 95% CI: 1.41, 2.63) and blisters (OR=1.57, 95% CI: 1.13, 2.18) than nonsmokers. These findings suggest that the influence of smoking is greater for conditions associated with overuse injuries than single, high-energy impacts.

Just as smoking may have a physiological basis for increased susceptibility to injury, so too may it play a role in healing. A population-based case-control study of healing of tibial shaft fractures by Kyrö et al. (1993) found that smokers had a significantly longer time to clinical union and a higher incidence of delayed union. In addition, smokers were found to have a 4.1-fold risk of tibial shaft fracture caused by low-energy trauma, relative to non-smokers ($p<0.01$). Other factors associated with delayed union and non-union include open fracture and female gender. Similar results were found in Cobb et al.'s study of smoking and non-union after ankle arthrodesis (1994): a history of cigarette smoking at the time of surgery resulted in a relative risk of 7.9 (95% CI=1.5, 41.9) for non-union when controlling for the presence of diabetes, cardiovascular disease, hypertension, non-steroidal anti-inflammatory drug use, and steroid use. These findings of delayed or abnormal bone healing are also supported by the detrimental effect smoking has on spinal fusion, for which Brown et al. found the nonunion rate to be five times as high in smokers as in non-smokers (1986).

The etiology of smoking's effects suggested by Kyrö et al. focus on limiting the reactive increase of blood flow following injury. Another possible cause could be the reduced strength of the tibia of smokers because of smoking-induced osteoporosis. Such a condition is highly prevalent among women who smoke one pack of cigarettes a day throughout adulthood and as a result experience a 5 to 10 percent deficit in bone density by the time of menopause (Hopper and Seeman, 1994). A recent meta-analysis of the association between smoking, bone mineral density, and hip fracture identified a "cause and effect" relationship among postmenopausal women (Law and Hackshaw, 1997). The authors estimated that the cumulative risk of hip fracture in English women was about 50% greater in smokers and that 13% of hip fractures are attributable to smoking. Interestingly, adjusting for many of the factors associated with hip fracture (e.g., body mass index, exercise, estrogen use) did not alter the results, suggesting that smoking acts directly on bone.

An additional health effect associated with smoking is tooth loss. In his review of smoking, bone density, and tooth loss, Johnston (1994) concludes that smokers have poorer oral hygiene (in terms of calculus deposition, debris, and staining) and fewer teeth than non-smokers. However, the etiology of tooth loss is not clear: smoking may act directly through the toxicity of tobacco smoke and gum inflammation or indirectly through the loss of underlying bone support. Also, smoking may simply be an indicator of decreased concern for personal health, as evidenced by poorer oral hygiene, rather than a direct effect of tobacco.

The effect of smoking appears to vary based on the specific type of injury or musculoskeletal disorder under study. For example, the few studies of fracture and non-union identified highly significant odds ratios ranging from 4.1 to 7.9. In comparison, much more modest estimates of effect were found for studies of low-back pain (OR=1.2-3.0), carpal tunnel syndrome (OR=1.6) and lower extremity injury (OR=1.9). Differences in the magnitudes of effect may be associated with the degree to which psychosocial and physiological factors contribute to the incidence of these disorders.

C. Potential mechanisms relating smoking and musculoskeletal disorders

Amoroso et al. (1996a) suggest tobacco use is related to both psychosocial and physiological factors that may alter the risk of musculoskeletal injury or disorder. The physiological mechanism proposed recognizes biological changes in the body resulting from tobacco use, thereby increasing the injury susceptibility for any given hazard. The psychosocial mechanism suggests that smokers tend to increase their exposure to potential hazards for injury through high-risk behaviors. This latter mechanism is akin to what Sacks and Nelson (1994) refer to as "confounding factors" that are primarily personality and behavioral characteristics and typically difficult to control for in epidemiological investigations. Several studies, for example, have identified smokers to be more nervous, anxious, depressed, obsessive, and prone to hostility relative to non-smokers (Hall et al., 1993). Other reports find smokers more likely to engage in risk-taking behaviors, such as seat belt non-use and drinking and driving (Eiser et al., 1979). These behaviors indicate that smoking may be an indicator for high-risk behavior in itself, independent of the psychosocial factors (e.g., race, education, occupation) that might contribute to increased exposure to hazardous environments for potential injury. Eiser et al. suggest that smokers make different decisions regarding their behavior and its consequences, as opposed to the belief that smokers are fundamentally different than non-smokers.

Based on our review of published studies, we identified 17 studies that adequately discuss potential biological or physiological mechanisms of action relating smoking and susceptibility to injury or musculoskeletal disorders (Table 2). However, it is not known which of the effects are primary and which are secondary, or the degree to which the effects act independently or interactively. Some of the studies suggest the possibility that smokers may be constitutionally or emotionally biased to complain of low back pain (Frymoyer et al., 1980) or that nicotine's effect "... alters the perception and threshold for pain, increasing the reporting of pain among smokers" (Brage and Bjerkedal, 1996). Other studies suggest specific components of cigarette smoke (e.g., nicotine, carbon monoxide, hydrogen cyanide) (Silverstein, 1992) or mechanisms (e.g., direct damage to the fibroblast macrophage system; vasoconstrictive effects diminishing nutritional blood flow; inhibition of epithelialization) (Mosely et al., 1978) that may increase susceptibility.

Insert Table 2 here

As the above review indicates, there is reasonable evidence that tobacco and its constituents may affect wound healing as well as potentially increase the risk of an injury occurring. Alcohol may also play a significant role in the healing process independent from that of tobacco. For example, alcohol is known to reduce osteoblastic activity and bone formation (Diamond et al., 1989) and influences malnutrition and hormonal/metabolic disturbances (Nyquist et al., 1997). However, confounding factors associated with alcoholism (e.g., nutritional deficiencies, liver damage, hypogonadism) limit the degree to which alcohol use independently can be associated with the higher incidence of osteoporosis and fractures (Laitinen and Valimaki, 1991). Nonetheless, the high correlation between alcohol and tobacco use (Maletzky and Klotter, 1974) suggests that the effects of each should be considered independently as potential contributors of injury.

In examining the relationship of tobacco use to disability, rather than the incidence of injury, the key issue is to observe the role of smoking on the development of disability following initial injury. The delayed or incomplete healing is one potential mechanism whereby smoking may increase the risk of disability. If one is able to control for some of the behavioral aspects that might affect the rehabilitation stage, the hypothesis that smoking is a direct and independent risk factor for disability may be considered. The following section outlines a potential model to portray the transition from an injured status to a disabled status.

D. Proposed model of physical disability following the incidence of a musculoskeletal disorder

Based on our review, we have summarized the theoretical mechanisms that relate a musculoskeletal disorder with development of a long-term physical disability (Figure 1). The primary mechanisms are based on behavioral and occupational characteristics of the individual and physiological aspects of the disorder and healing. These mechanisms represent the complex nature of the association and attempt to account for many of the potentially confounding factors that limit many of the epidemiologic investigations into both tobacco use and musculoskeletal disorders. Furthermore, the specific predictors represent the multifactoral components (i.e., clinical, sociodemographic, ergonomic, psychological, and economic) that have recently been associated with work-related disability following musculoskeletal disorders (Katz et al., 1997; Bongers et al., 1993; Cats-Baril and Frymoyer, 1991; Feuerstein and Thebarge, 1991).

Variables representing the biological effects of smoking (e.g., vasoconstriction, hypoxia, etc.) have been represented as components of the disorder/healing characteristic. Recurrent trauma or reinjury may also influence the ability to heal and development of disability. Another component of this characteristic worthy of mention is the presence of an alcohol-related comorbidity, which may act independently or interactively with other components of the model. The individual characteristics are composed of both inherent traits (e.g., age, race/ethnicity, sex, physical stature) as well as various measures of socioeconomic status (e.g., income, education, family status). Behavioral characteristics are represented by tobacco and alcohol consumption. Also, a health practices index representing parameters related to diet, sleep, and exercise (Kroutil et al., 1994) has been included. Lastly, various occupational characteristics that have been associated with musculoskeletal disorders are included to represent ergonomic as well as internal (e.g., job satisfaction) and external (e.g., job stress) exposures.

A variable that is expected to act as a modifier in the development of disability is the availability of workers' compensation. Compensation has been associated with an increased rate of unemployment, a prolonged time off work, and greater levels of pain and disability among patients with low back pain, lower extremity fracture, and upper extremity disorders (Coste et al., 1994; Greenough and Fraser, 1989; Cheadle et al., 1994; MacKenzie et al., 1997; Katz et al., 1997; Higgs et al., 1995; Nathan et al., 1993). The implication that compensation retards and impairs recovery from injury has resulted in the proposed existence of a "compensation neurosis" (Greenough and Fraser, 1989). The condition of compensation neurosis is defined as "... the psychological symptoms occurring after an injury in which a compensation claim is possible or pending, and in which such a claim is thought to be the most significant maintaining cause of the symptoms" (Weighill, 1983).

Although military personnel, subjects of many of the studies, participate in a relatively non-adversarial compensation system compared to that of the private sector, the existence of a compensation neurosis may remain, though to a lesser degree. Contrary to many civilian workers, military personnel often times prefer, if possible, to remain on the job and avoid disability "boarding" (i.e., evaluation by military physicians to determine disability status), which may result in discharge from the service. The prospect of limited compensation from the service and/or Veterans Affairs, the possibility of losing benefits associated with military service, and the difficulty in finding comparable work in the civilian work environment provide a daunting challenge to many soldiers attempting to cope with a newly acquired physical disability. Thus, military personnel provide an opportunity to study disability without the confounders associated with civilian workers compensation systems.

The model is intended to incorporate several of the concepts presented in Amoroso et al.'s sketch of potential mechanisms for injury risk (1996c). In presenting plausible mechanisms for elevated injury risks among smokers, the authors suggested the interaction of physiological and psychosocial factors. All of the variables in their model are considered to affect either of these causal pathways. However, when adapted to our model that intends to account for factors related to development of long-term disability, those elements that support an increased exposure to hazards have been de-emphasized while the index of health practices has been included. This difference is intended to reflect the difference in outcome, disability rather than injury, and what mechanisms might affect the opportunity for healing rather than exposure to hazards.

E. Conclusion

This review of the literature clearly identifies smoking to be a significant risk factor for several commonly occurring musculoskeletal disorders, including low-back pain (OR=1.2-3.0), lower extremity injury (1.9), carpal tunnel syndrome (1.6), and fracture/non-union (4.1-7.9). We present reasonable evidence that tobacco and its constituents may affect wound healing as well as potentially increase the risk of an injury occurrence. Also, a multifactoral model portraying the injury-to-disability transition is offered to clinicians and researchers to assist their consideration of modifiable risk factors that endanger a successful recovery following injury.

Despite the depth of research on health effects relating to tobacco use (U.S. DHHS, 1989), the inability to control for potential confounders (e.g., health practices, risk-taking behavior, alcohol use, physical demands, stress, socioeconomic status) and risk factors (e.g., condition severity) has limited our ability to understand the degree to which tobacco use may be associated with injuries and musculoskeletal disorders and their subsequent evolution into a physical disability. Also, because of limited appreciation of the influence of tobacco on injury outcomes, this association is infrequently tested or reported in injury research (Amoroso et al., 1998b). This review provides evidence that researchers should consider smoking as a potentially important confounder in injury research.

Table 1. Epidemiological evidence of smoking's effect on musculoskeletal disorders and acute injuries

Author(s)	Study design/ analytic technique	Population	Outcome	Smoking Covariate	Measure of Effect (RR, OR) for Smoking and 95% CI / p-value		
Law and Hackshaw, 1997	Meta-analysis	Smokers and nonsmokers by age	Risk of hip fracture	Age: 50 60 70 80 90	0.96 (0.81, 1.13) 1.17 (1.05, 1.30) 1.41 (1.29, 1.55) 1.71 (1.50, 1.96) 2.08 (1.70, 2.54)		
Rothenbacher et al., 1998	Prospective cohort/ Cox proportional hazards	4796 construction workers in Germany	Early retirement due to physical disability	Never smoker Former smoker Pipe/cigar smoker Current smokers (all) 1-19 cigarettes/day 20-29 cigarettes/day ≥30 cugarettes/day Unknown	1.0 1.2 (0.8-1.7) 1.1 (0.5-2.5) 1.3 (1.0-1.8) 1.3 (0.8-2.0) 1.5 (1.0-2.3) 1.6 (1.0-2.8) 1.2 (0.8-1.8)		
Amoroso et al., 1996b¶	Prospective cohort/ logistic regression	Groups of 449 and 848 Army basic airborne (parachute) trainees and 409 experienced airborne soldiers	Any musculoskeletal injury requiring visit to clinic or hospital	Nonsmoker Current smoker Former smoker (<6 months) Former smoker (>6 months) Chewing tobacco use	1.00 0.49 (0.11-2.13) NS NS 1.52 (0.94-2.47)		
Dettori et al., 1996	Prospective cohort/ logistic regression	165 female Army basic trainees over an 8 week training period	Any musculoskeletal injury (MSI), overuse injury, and traumatic injury	Smoking status Current smoker vs Nonsmoker Former(<6 mos vs Nonsmoker) Former(>6 mos) vs Nonsmoker	MSI 3.1 (1.1-8.7) 2.8 (1.1-7.0) 1.3 (0.2-5.9)	Overuse 2.1 (0.9-5.2) 2.4 (1.1-5.5) 1.6 (0.4-7.1)	Traumatic 2.1 (0.8-5.7) 1.4 (0.6-3.5) 1.5 (0.3-7.1)
Reynolds et al., 1996	Prospective cohort/ logistic regression	218 infantry soldiers on a 100-mile road march	Any injury, Blisters, Time-loss injury	Smoking	Any Injury 1.93 (1.4-2.6)	Blisters 1.57 (1.1-2.2)	Time-loss Inj NS
White, 1995[b]	Prospective cohort/ logistic regression	198 senior military officers followed for 10 months	Musculoskeletal disorder incidence of lower extremity and any body region	Former smoker vs. Nonsmoker Current smoker vs. Nonsmoker	Any Body Region 1.67 (0.75-3.70) 2.31 (0.64-8.35)	Lower Extremity 4.02 (1.19-13.6) 10.70 (2.12-54.4)	
Hubert and Fries, 1994	Prospective cohort/ linear regression	299 university facutly and staff; 407 members of runners club (all 50-80 years old)	Physical disability	Pack-years smoked	University p<0.05	Runners Club NS	
Reynolds et al., 1994	Prospective cohort/ logistic regression	181 light infantry soldiers followed over 1 year	Lower extremity and low-back training injuries	Smokers vs. Nonsmokers	3.0 (1.5, 6.1)		
Snoddy and Henderson, 1994	Prospective cohort/ analysis of variance	649 basic and advanced infantry trainees over a 13 week cycle	No. of medical visits, Profile time, Training completion	Smoking	No. med visits p=0.006	Profile time p=0.016	Train. compl. p=0.023

Author(s)	Study design/ analytic technique	Population	Outcome	Smoking Covariate	Measure of Effect (RR, OR) for Smoking and 95% CI / p-value
Viikari-Juntura et al., 1994 ¶	Prospective cohort/ logistic regression	1832 men working at offices, machines, or construction	Change in neck trouble over 3 years	Ex-smoker vs. Nonsmoker Current smoker vs. Nonsmoker	None-Mod: 1.2 (0.7-2.1); 1.2 (0.8-1.9) None-Severe: 1.5 (0.8-2.9); 1.8 (1.0-3.2) PersistSevere: 1.0 (0.5-2.0); 1.4 (0.7-2.8)
Jones et al., 1993	Prospective cohort/ logistic regression	303 young men in 12 week Army infantry basic training	Lower extremity musculoskeletal injury	<10 cigarettes/day ≥10 cigarettes/day	1.0 1.9 (1.1-3.3)
Ryan et al., 1992	Prospective cohort/ Cox proportional hazards	2537 postal employees	Occupational injuries	Smokers vs. Nonsmokers	1.40 (1.11-1.77)
Battié et al., 1989	Prospective cohort/ Cox proportional hazard	3020 aircraft manufacturing employees	Reported back injury at work	Smoking at time of initial physical exam	1.4 (p=0.002)
Biering-Sørensen & Thomsen, 1986	Prospective cohort/ logistic regression	442 men and 478 women of 30-, 40-, 50- and 60-yo	First-time experience of low-back trouble	More frequent daily smoking	All: p<.05 Workers: p<.05
Leigh, 1985	Prospective cohort/ logit regression	~ 150 adults in the Michigan Panel Study of Income Dynamics	become disabled during the previous year	Smoking	p<0.05
White, 1995¶	Retrospective cohort/ analysis of variance	178 senior military officers over 5 years	Musculoskeletal disorder incidence of lower extremity (LE) and any body region	Smoking status Never smoker Former smoker Current smoker	Any (trend: p=.45): 1.56; 1.35; 1.07 LE (trend: p=.14): 0.75; 0.42; 0.33
Cobb et al., 1994	Case-control/ logistic regression	22 cases (nonunion) and 22 controls (fusions)	Nonunion after ankle arthrodesis	Smoking at time of surgery	7.9 (1.5-41.9)
Kyrö et al., 1993	Case-control/ χ^2 test	135 patients (72 smokers vs. 63 non-smokers)	Tibial shaft fracture caused by low-energy injury	Smokers vs. Nonsmokers	4.1 (p<0.01)
O'Connor and Marlowe, 1993	Case-control/ Student t test and χ^2 test	160 male US Army soldiers in basic training	Self-reported low back pain	Smokers vs. Nonsmokers	p=0.02
Brison, 1990	Case-control/ logistic regression & χ^2 for trend	582 persons with MVC and 1072 who did not	Motor vehicle crash	Smokers vs. Nonsmokers	1.5 (p=.01)
Brown et al., 1986	Case-control/ χ^2 test	50 smokers and 50 nonsmokers with 2-level laminectomy and fusion	Pseudarthosis (surgical nonunion)	Smokers vs. Nonsmokers	5.0 (p<0.001)
Kelsey et al., 1984	Case-control/ logistic regression	325 cases age 20-64 and matched controls	Acute prolapsed intervertebral disc	Cigarette smoking (increase of average of 10 cigarettes/day)	1.2 (1.0-1.4)
Owen and Damron, 1984	Case-control/ two-way analysis of variance	64 female nurses (32 back injured, 32 not)	On the job low back injury during manual transfer	Smoking among injured vs. non-injured nurses	p<0.05

Author(s)	Study design/ analytic technique	Population	Outcome	Smoking Covariate	Measure of Effect (RR, OR) for Smoking and 95% CI / p-value		
Frymoyer et al., 1980	Case-control/ Student t test and χ^2 test	3920 adult patients (18-55 years old)	Clinic visit for low-back pain	Smokers vs. Nonsmokers	p<0.001		
Tanaka et al., 1997	Cross-sectional/ logistic regression	1988 National Health Interview Survey, Occ. Health Supplement	"Medically called" carpal tunnel syndrome	Ever vs. Never smokers	1.64 (1.03, 2.62)		
Brage and Bjerkedal, 1996	Cross-sectional/ logistic regression	6681 Norwegian adults in health survey	Musculoskeletal pain	Current smoking	Neck/upp. limb 1.87(1.6-2.3)	Back 1.84(1.5-2.3)	Lower limb 1.37(1.1-1.7)
Nathan et al., 1996	Cross-sectional/ χ^2 and regression	1464 American industrial workers	Definite carpal tunnel syndrome	Current use of tobacco Lifetime use of tobacco	26% greater in workers with CTS (p<0.05) independent risk factor in regression for females 19% greater in workers with CTS (p<0.05)		
Finkelstein, 1995	Cross-sectional/ logistic regression	129 fire fighters and 346 police officers (males)	Self-reported back pain	Current smoker	1.88 (1.13-3.11)		
White, 1995*	Cross-sectional/ logistic regression	1291 automotive manufacturing workers	Shoulder disorder symptoms	Former smoker vs. Nonsmoker Current smoker vs. Nonsmoker	1.20 (0.75-1.91) 1.46 (1.01-2.13)		
Boshuizen et al., 1993	Cross-sectional/ prevalence differences	4054 Dutch men aged 25 to 55 years	Back pain in construction workers	Current smoker vs. Nonsmoker Former smoker vs. Nonsmoker	3.1 (-1.7-8.0)* 9.8 (-4.1-15.6)*		
Mäkelä et al., 1993 ¶	Cross-sectional/ logistic regression	7217 Finnish adults using a two-stage (screening and physical) cluster sample	Reduced working capacity, occasional and regular assistance for ADLs	Smoking	NS		
Friedl et al., 1992	Cross-sectional/ logistic regression	2312 active duty Army women	Diagnosed with a stress fracture	Current smoker vs. Nonsmoker	1.91 (1.45-2.51)		
Tsai et al., 1992	Cross-sectional/ logistic regression	10,350 employees of Shell oil manufacturing facilities	Low-back injury; nonlow-back injury	Smoking (current vs. never/ former)	Low-Back Injury 1.54 (1.20-1.98)	Non-Low-Back Injury 1.23 (1.00-1.51)	
Heliövarra et al., 1991	Cross-sectional/ logistic regression	8000 Finnish adults using a two-stage (screening and physical) cluster sample	Sciatica and unspecified low-back pain	 Women (30-49 years old) Women (50-64 years old) Men (30-49 years old) Men (50-64 years old)	Former 1.0 (0.6-1.8) 0.7 (0.4-1.3) 1.9 (1.1-3.2) 1.3 (0.8-2.1)	Light 1.2 (0.7-2.1) 1.2 (0.7-2.1) 2.0 (1.2-3.6) 1.3 (0.8-2.2)	Heavy 0.7 (0.3-1.9) 2.7 (1.1-6.9) 1.7 (1.0-3.1) 1.9 (1.1-3.9)
Mäkelä et al., 1991 ¶	Cross-sectional/ logistic regression	8000 Finnish adults using a two-stage (screening and physical) cluster sample	Chronic neck syndrome	Smoking status Former smoker vs. Nonsmoker Current smoker vs. Nonsmoker	30-64 years old 1.20 (0.94-1.53) 1.25 (0.99-1.57)	>64 years old 1.28 (0.77-2.11) 1.23 (0.72-2.11)	
Deyo and Bass, 1989	Cross-sectional/ logistic regression	10,404 persons surveyed by NHANES-II with physical exam	Low-back pain within past year with ≥ 1episode of near daily pain for ≥ 2 weeks	Smoking (pack-decades)	Each Increment 1.05 (p<0.0006)	High vs. Low 1.36	

Author(s)	Study design/ analytic technique	Population	Outcome	Smoking Covariate	Measure of Effect (RR, OR) for Smoking and 95% CI / p-value	
Riihimäki et al., 1989¶	Cross-sectional/ univariate logistic regression	216 concrete reinforcement workers and 201 house painters	12-month prevalence of sciatic pain	Nonsmokers Ex-smokers Smokers	1.0 1.2 (0.9-1.7) 1.1 (0.7-1.7)	
Saraste and Hultman, 1987	Cross-sectional/ χ^2 analysis	2872 Swedish citizens aged 30-59	Low-back pain	Smoking	p<0.05 (50-59 yo males, only)	
Svensson et al., 1983	Cross-sectional/analysis of covariance	940 randomly selected men from 40 to 47 years old	Low-back pain	Smoking	p<0.05	
Vessey et al., 1990	Case series/ referral rate and χ^2 test for trend	154 women of childbearing age	Referral to hospital for management of carpal tunnel syndrome	Cigarette smoking (per day) Never and former 1-14 15-24 25+	20-44 yo (trend: p<.01) 0.45 0.57 0.77 1.24	45+ yo (trend: p<.05) 1.28 0.87 2.35 4.34

NS: Not statistically significant at α=0.05; ¶ No or marginal association between outcome and smoking; * Age adjusted prevalence difference in percentage and 90% confidence interval; a, b, c: individual studies within dissertation

Table 2. Studies suggesting biological mechanisms of tobacco use and increased injury or musculoskeletal disorder susceptibility

Reference	Health Effect	Potential Mechanisms
Law and Hackshaw, 1997	hip fracture	- formation of new bone is impaired by exposure to nicotine; - smoking may reduce calcium absorption; - smoking results in greater risk of falls among the elderly (see Slade, 1995)
Frymoyer et al. (1980)	low-back pain	- smokers may be constitutionally or emotionally biased to complain of low-back pain; - significant hormonal and/or other alterations may increase low-back pain; - smoking produces other problems (e.g., chronic cough) that lead to a greater incidence of low-back pain (via mechanical stresses)
Braje and Bjerkedal (1996) and White (1995)	musculoskeletal pain; degeneration of muscle, joints, and discs	- nicotine-induced reduction in blood flow and oxygen; - nicotine may modify the perception and threshold for pain
Slade (1995)	falls in elderly	- nicotine: chronic effect of relaxing skeletal muscles might impair the ability to respond to momentary changes in load and balance
Marti et al. (1988)	reduced performance during maximal physical exertion (endurance)	- permanent increase in carboxyhemoglobin may reduce the oxygen-transport capacity of blood;
Ernster et al. (1995)	facial wrinkling	- topical drying of skin; - vascular or connective tissue damage; - decreased capillary and arteriolar blood flow in the skin; - damage to lung collagen and elastin; - decrease in vitamin A (protect against oxygen radicals that damage DNA and connective tissue)
Mosely et al. (1978)	impaired wound contraction in the rabbit ear	- direct damage to the fibroblast macrophage system; - vasoconstrictive effects diminishing the nutritional blood flow; - inhibition of epithelialization
Siana et al. (1989)	poor cosmetic results following surgical incision	- smoking may increase tension in broad scars during the healing process
Sweet and Butler (1979)	localized osteitis following third molar surgery	- introduction of foreign substance to contaminate surgical site; - suction applied to cigarette might dislodge the clot from the alveolus and interrupt healing; - carbon monoxide increases artery wall permeability, possibly affecting clotting
Silverstein (1992)	skin flap survival	- nicotine: vasoconstriction reduces nutritional blood flow to the skin, resulting in tissue ischemia and impaired healing of injured tissue; increases platelet adhesiveness, raising the risk of thrombotic microvascular occlusion and tissue ischemia; reduction of red blood cells, fibroblasts, and macrophages; - carbon monoxide: diminishes oxygen transport and metabolism; - hydrogen cyanide: inhibits enzyme systems for oxidative metabolism and oxygen transport
Knapik et al. (1997)	foot blisters	- nicotine-induced vasoconstriction in the peripheral circulation and atherosclerotic lesions may reduce the skin's ability to respond to frictional forces

Reference	Health Effect	Potential Mechanisms
Kyrö et al. (1993) and Cobb et al. (1994)	delayed union and non-union of tibial shaft fractures and ankle fractures	- smoking may impair the reactive increase in blood flow to the injured tibia through decreased mean oxygen partial pressure and oxygen saturation levels, or - decreased mean digital blood-flow velocity and blood flow in the cutaneous microcirculation
Brown et al. (1986)	surgical nonunion of spinal fusion	- inadequate oxygenation of blood flow to the bone graft may form fibrous tissue rather than bone
Johnston (1994)	bone fracture	- bones may weaken directly through tobacco's toxicity; or - smoking's effect of reducing body weight may thin and weaken bones
Hopper and Seeman (1994)	bone loss	- increased bone resorption;

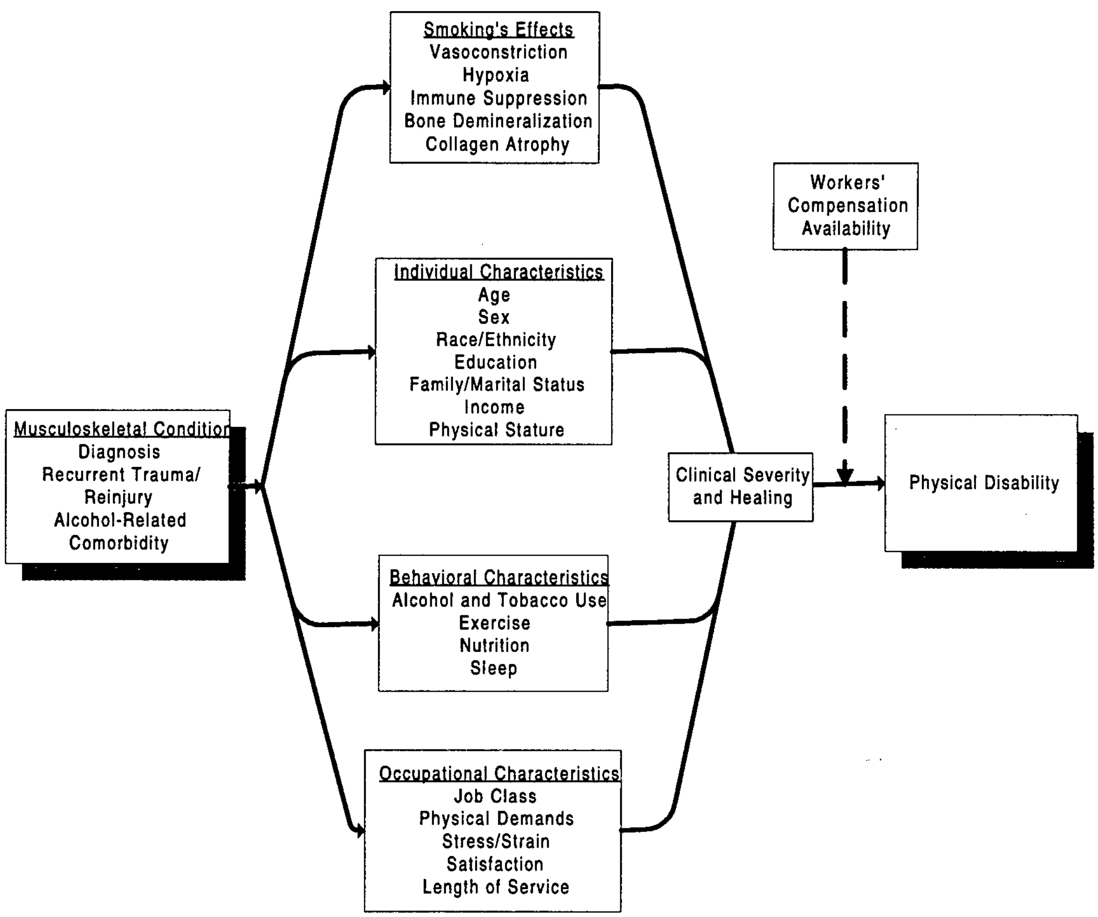


Figure 1. Theoretical Model

CHAPTER 2: INTRODUCTION AND METHODOLOGY

2.1 Overview

Musculoskeletal disorders are a primary source of morbidity, lost time, and lost readiness in the military. In 1992, the combined categories of accidents/other injuries and musculoskeletal/connective tissue disorders accounted for the largest proportion of hospitalizations in the Army, slightly more than 30 percent (Smith et al., 1996). Despite the high incidence of these disorders, little is known about their natural history and long-term outcomes, the likelihood that they will result in permanent disability necessitating medical discharge, or those factors associated with an increased likelihood of disability.

In order to reduce the long-term disability following the incidence of musculoskeletal disorders, a better understanding of predictors of disability and subsequent interventions are required. One potential risk factor for disability suggested by the medical literature is tobacco use. A number of physiological and psychosocial mechanisms relating smoking to injuries and musculoskeletal disorders have been hypothesized to support this notion. The role of several other key factors, including physical demands and stress associated with occupational exposures, health practices, and gender have yet to be fully investigated among cohorts over extended lengths of time.

This study examines the natural history of hospitalized musculoskeletal disorders that have a high incidence or a strong biological basis of being influenced by tobacco use. Of primary interest are risk factors for subsequent long-term disability, including the potential role of tobacco use. The objectives of this study are to: 1) examine long-term outcomes following hospitalization for specific musculoskeletal disorders in the U.S. Army from 1989 to 1996; 2) investigate risk factors affecting the likelihood of disability following musculoskeletal hospitalization, including smoking and other behavioral, individual, occupational, and disease characteristics; and 3) to evaluate the effect of cigarette smoking on the development of physical disability among persons hospitalized with a musculoskeletal disorder. Findings should provide a basis for interventions directed at disability prevention in the Army and active civilian populations, potentially involving the habit of smoking during the rehabilitation process.

The methodology described in this chapter is innovative in a number of aspects. First, it makes use of a collection of administrative databases that have not previously been combined to this extent for scientific research purposes. As the use of these databases for epidemiologic study is still in its infancy, this investigation is the first to attempt to link databases regarding demographic characteristics (i.e., personnel), medical characteristics (i.e., hospitalization), health behaviors (i.e., health risk assessment), and health outcome (i.e., disability) using unique personal identifiers. The linkage of these data, particularly to the extent of information included, would not be available in civilian-based databases. Nor would it be available through public-use data files because of security and confidentiality restrictions. Recognition of these issues highlights the unique opportunity to address my research questions.

Second, this study retrospectively follows a service-wide and therefore very large cohort over an extended period of time (potentially up to nine years) to follow the long-term outcome of hospitalized musculoskeletal disorders. The identification of an existing cohort with detailed records such as these is extremely rare. A retrospective cohort design was implemented to take full advantage of the person-years available. In addition, the retrospective design permits research to be performed for a fraction of the cost that would have been required for a prospective study to address the same concerns.

Third, the use of military data provides a chance to capture all conditions of interest, regardless of whether they are primarily associated with work activities or those occurring off duty. By handling all subjects without regard to their work-relatedness, studies of military personnel largely avoid confounding effects associated with worker's compensation, attorney involvement, and litigation that are especially an issue for musculoskeletal disorders in the private sector. In addition, the determination of disability in the Army is largely devoid of the antagonistic employee-employer relationship and fault-finding that biases much of disability-related research involving civilian workers. By minimizing these confounders, this study should provide an accurate depiction of those factors associated with the development of physical disability.

<u>Chapter Organization:</u> The following sections of this chapter describe the methods

used in this dissertation. The next section introduces the study hypotheses (2.2), followed by the study design (2.3) and data sources (2.4). Next, issues related to variable selection (2.5), such as file construction, are addressed. The analytic plan (2.6) reviews the methods and rationale used for the descriptive and multivariate analyses. The statistical techniques (2.7) are described for survival analyses applied to this cohort study. Lastly, the intent and use of this study is summarized (2.8).

This chapter, which is preceded by a review of the literature in the form of a review article (Chapter 1), is followed by two analytical manuscripts addressing first the natural histories of musculoskeletal disorders and risk factors for disability (Chapter 3) and then the effect of smoking on musculoskeletal-related disability (Chapter 4). A final summary and conclusion chapter (Chapter 5) discusses the results of the analysis, their clinical and policy implications, and areas for future research.

2.2 Study Hypotheses

The following hypotheses are assessed in this research:

H1: A combination of demographic, behavioral, psychosocial, occupational, and clinical characteristics are associated with an increased risk of development of physical disability among military persons hospitalized with a musculoskeletal disorder. Persons at greater risk for disability include those:

A) hospitalized for back-related diagnoses;

B) of older age;

C) of female sex;

D) in a lower pay grade/rank;

E) with less education;

F) in physically demanding occupations;

G) who experience greater job-related stress;

H) who perceive less job satisfaction;

I) with poorer health practices;

J) who experience recurrent musculoskeletal-related hospitalizations.

H2: Among personnel hospitalized for musculoskeletal disorders, those with a history of smoking are at greater risk for medical disability discharge than non-smokers, controlling for other risk factors.

H3: Among personnel hospitalized for musculoskeletal disorders, there is a dose-response relation between smoking exposure and cumulative risk of disability.

2.3 Study Design

A retrospective cohort design was used to follow U.S. Army personnel from their initial musculoskeletal-related hospitalization, which occurred between the years 1989 and 1996, through the development of disability, up to 1997. This study design enabled me to assess the roles of diverse covariates with a specific outcome of interest, the development of physical disability, in an open cohort (Figure 1). Unique identifiers (scrambled social security numbers to preserve confidentiality) permitted the linkage of information on individual subjects across databases. In effect, the identifiers allowed me to track the natural history of a subject's condition from initial hospitalization across follow-up hospitalizations and potentially to a level of disability that results in a medical disability discharge from the service. Health risk appraisal data was used to incorporate behavioral influences beyond the personal characteristics and occupational exposures that are commonly utilized in epidemiologic studies. The completeness of the Army's administrative databases offered excellent follow-up with minimal loss of cohort subjects.

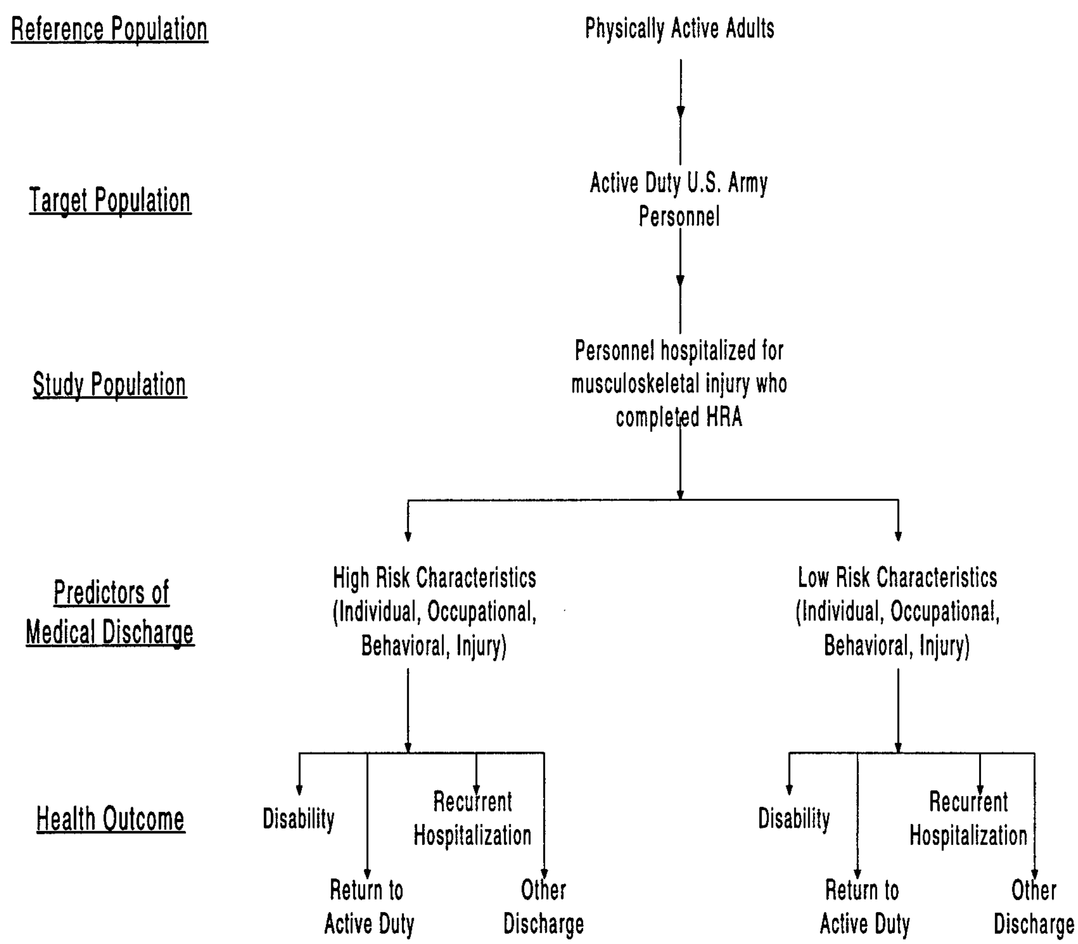


Figure 1. Retrospective cohort study design

2.3.1 Study Population

Subjects for this study were drawn from the U.S. Army. To be included in the study, cohort subjects must have met several criteria: 1) been on active duty at the time of hospitalization; 2) been hospitalized for a specific musculoskeletal disorder or severe sprain/strain during the period 1989 to 1996 (Table 1); and 3) completed a health risk appraisal (HRA) at some point during the same time period. There were 16,348 persons who met those initial criteria. Because the goal of the study was to capture persons at their first hospital admission for one of the diagnoses of interest, those hospitalized for the same condition prior to 1989 (N=1053) or having a disability rating preceding the initial musculoskeletal hospitalization (N=27) were disqualified and eliminated from the cohort. The remaining subjects (N=15,268) were used in the analysis for the first analytic manuscript on natural history of musculoskeletal disorders and risk factors for disability. However, 148 subjects with no cigarette smoking data were eliminated for the second analytic manuscript on the effect of smoking on musculoskeletal-related disability. This resulted in a study population of 15,120 for this analysis.

2.3.2 Diagnostic Categories

Forty diagnoses were selected from the principal diagnosis field in the hospitalization database. Selection was based on either well-defined clinical symptoms (e.g., cruciate ligament injury) to permit an accurate diagnosis, or a high incidence (e.g., non-specific back pain) to insure adequate statistical power (Table 1). These 40 diagnoses were classified into 13 diagnostic categories (e.g., meniscal injury, rotator cuff injury) for analysis in the first and second manuscripts and were further classified into 4 functional groups (e.g., knee, back, overuse, and other musculoskeletal condition) for additional analyses in the first manuscript. Discussions with an injury researcher with experience in coding (Gordon Smith, MD, MPH, Johns Hopkins School of Hygiene and Public Health), a practicing orthopedist (Richard Hinton, MD, MPH, MPT, MEd, Johns Hopkins School of Medicine), and a practicing physiatrist (Tamara Lauder, MD, Johns Hopkins School of Medicine) were performed to develop the diagnostic categories and functional groupings that involve similar mechanisms of injury or healing. We decided not to examine all musculoskeletal injuries; rather we sought to focus on a group of clean diagnostic and clinical entities since the whole group of musculoskeletal conditions cover a broad range of widely discrepant disorders.

Diagnoses included both "acute" injuries within ICD-9-CM codes 836, 840, or 844 and "chronic" conditions (710-739, 354) that represent similar clinical presentations. For instance, within the Collateral Ligament Injury category, diagnoses include both sprain/strain of cruciate ligament of knee (ICD-9-CM 844.2) as well as old disruption of anterior cruciate ligament (717.83). This is because such injuries may not be reported to hospital immediately, or even for months later, and the same injury could then be assigned to either the acute injury or chronic musculoskeletal code when the patient does present to hospital.

Table 1 also includes the percentage of musculoskeletal admissions that involved a procedure. There is a wide variation that illustrates different treatment regimens associated with various diagnoses. For example, hospitalizations for knee and overuse conditions very often involve procedures (80-93%). However, procedures are much less common with back conditions (e.g., 21% for nonspecific back pain and 51% for intervertebral disc degeneration), reflecting the largely unknown etiology and limited treatment options for these conditions.

Table 1. Functional Groups and Diagnostic Categories of ICD-9-CM Codes for Musculoskeletal Disorders and Sprain/Strains

Functional Group	Diagnostic Category (% with procedure)	ICD-9-CM Code
1. Back conditions	A. Non-specific back pain (21.4%)	724.2 Lumbago 724.5 Backache, unspecified
	B. Displacement of intervertebral disc (74.2%)	722.0 Displacement of cervical intervertebral disc without myelopathy 722.1 Displacement of thoracic or lumbar intervertebral disc without myelopathy (includes .1, .10, .11) 722.2 Displacement of intervertebral disc, site unspecified, without myelopathy
	C. Degeneration and other disc disorders (50.7%)	722.4 Degeneration of cervical intervertebral disc 722.5 Degeneration of thoracic or lumbar intervertebral disc (includes .51, .52) 722.6 Degeneration of intervertebral disc, site unspecified 722.7 Intervertebral disc disorder with myelopathy (includes .70, .71, .72, .73) 722.8 Postlaminectomy syndrome (includes .80, .81, .83) 722.9 Other and unspecified disc disorder (includes .90, .91, .92, .93)
2. Knee conditions	D. Meniscal injury (92.9%)	717.0 Old bucket handle tear of medial meniscus 717.1 Derangement of anterior horn of medial meniscus 717.2 Derangement of posterior horn of medial meniscus 717.3 Other and unspecified derangement of medial meniscus 717.4 Derangement of lateral meniscus (includes .4, .40, .41, .42, .43, .49) 717.5 Derangement of meniscus, not elsewhere classified 836.0 Tear of medial cartilage or meniscus of knee, current 836.1 Tear of lateral cartilage or meniscus of knee, current 836.2 Other tear of cartilage or meniscus of knee, current
	E. Cruciate ligament injury (89.5%)	717.83 Old disruption of anterior cruciate ligament 717.84 Old disruption of posterior cruciate ligament 844.2 Sprain/strain of cruciate ligament of knee
	F. Collateral ligament injury (86.5%)	717.81 Old disruption of lateral collateral ligament 717.82 Old disruption of medial collateral ligament 844.0 Sprain/strain of lateral collateral ligament 844.1 Sprain/strain of medial collateral ligament
	G. Chondromalacia (79.9%)	717.7 Chondromalacia of patella

Functional Group	Diagnostic Category (% with procedure)	ICD-9-CM Code
3. Overuse conditions	H. Synovitis and tenosynovitis (91.5%)	727.0 Synovitis and tenosynovitis (includes .0, .00, .01, .02, .03, .04, .05, .06, .09)
	I. Carpal and cubital tunnel syndromes (88.5%)	354.0 Carpal tunnel syndrome 354.2 Lesion of ulnar nerve (Cubital tunnel syndrome)
	J. Rotator cuff injury (84.2%)	726.1 Rotator cuff syndrome of shoulder and allied disorders (includes .1, .10, .11, .12, .19) 840.3 Infraspinatus (muscle) (tendon) 840.4 Rotator cuff (capsule) 840.5 Subscapularis (muscle) 840.6 Supraspinatus (muscle) (tendon)
4. Other MS conditions	K. Ganglion and cyst of synovium, tendon, and bursa (96.3%)	727.4 Ganglion and cyst of synovium, tendon, and bursa (includes .4, .40, .41, .42, .43, .49)
	L. Bunion and deformities of toe (92.4%)	727.1 Bunion 735.0 Hallux valgus (acquired)
	M. Malunion and nonunion of fracture (76.8%)	733.8 Malunion and nonunion of fracture (includes .8, .81, .82)

2.3.3 Study Outcomes

The outcome considered in this analysis was time (number of months) to disability discharge. Disability discharge was defined as having been assigned the following status at a medical evaluation board at some point between the initial hospitalization (between 1989 and 1996) and the end of 1997: 1) permanent disability/retirement (disability rating of at least 20% or having at least 20 years of service); 2) severance without benefits (disability rating of less than 20% and having less than 20 years of services); or 3) temporary disability. Because this study was designed to document the incidence of disability following musculoskeletal hospitalization, all medical discharges for disability were included, regardless of the primary cause or condition. Time to disability was determined from the point of the initial musculoskeletal hospitalization until the subject was medically discharged (defined as an "event"), censored for a non-medical discharge (e.g., honorable discharge, left of own accord), or censored because of the end of the follow-up period (Figure 2).

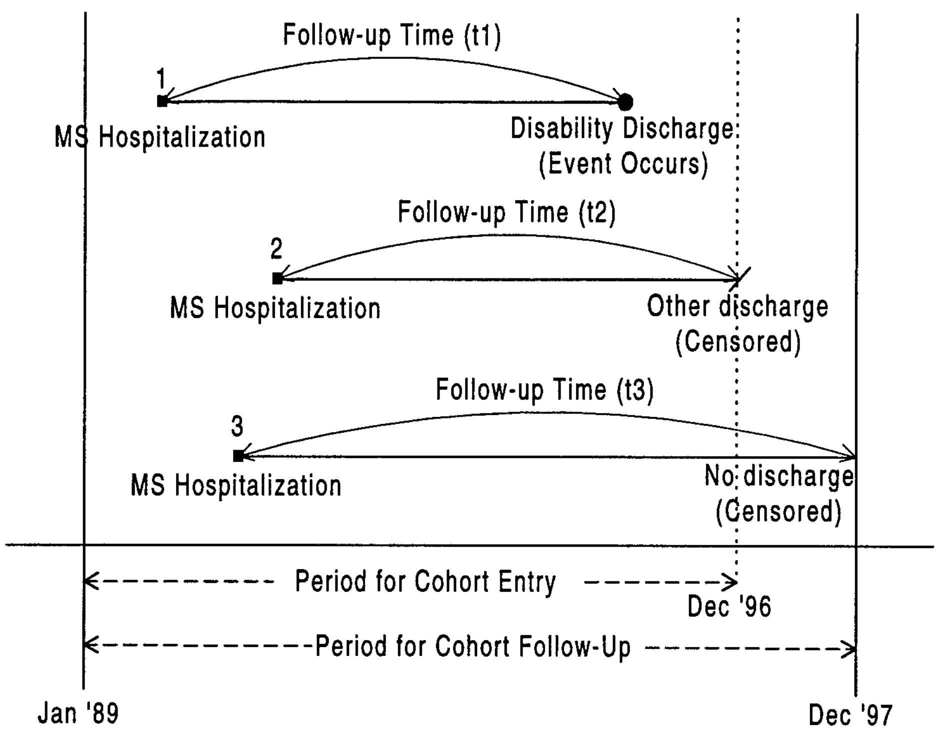


Figure 2. Outcome Classification and Follow-up Period

2.4 Data Sources

Data were obtained from the Total Army Injury and Health Outcomes Database (TAIHOD), which was recently created for injury prevention and women's health research by the U.S. Army Research Institute of Environmental Medicine (USARIEM). The TAIHOD is a collection of databases with the capacity for linkage of individuals using scrambled social security numbers (Amoroso et al., 1997a). This study made use of four types of data: demographic information, health outcomes (hospitalizations), functional outcomes (disability ratings), and health practices and behaviors as determined by health risk appraisal surveys. Composition of the necessary data required the linkage of six separate databases: personnel, loss from service, hospitalization, disability, health risk appraisal, and military occupational specialty/physical demands.

<u>Personnel and Loss:</u> The Defense Manpower Data Center database provides extensive demographic data for all active duty personnel in the Army from 1980 to mid-1997, including age, gender, race, ethnic group, rank, duty and primary military occupational specialty, education level, and length of time in service. An additional database, the loss file, includes information on former active duty members who have been released from the Army for various reasons, including medical disability discharge from the service. The loss file was fundamental to provide censoring information necessary in this study (e.g., the date people left the service). To coincide with the time period for which health risk appraisal data were available, personnel

records for the period 1989-1997 were used.

Hospitalization: The Army Individual Patient Data System captures data on every active duty Army soldier hospitalized from 1980-1997. This dataset includes variables for demographics, principal and secondary diagnoses by ICD-9-CM codes, external cause of injury codes, and dates of admission, among many other variables. Persons hospitalized with a principal diagnosis of a musculoskeletal disorder included in Table 1 and other criteria previously mentioned were eligible to enter the cohort. The existence of a recurrent hospitalization for an identical diagnosis and existence of an alcohol-related comorbidity in any of the eight diagnostic fields for any hospitalization were obtained from the hospitalization data as well.

Disability: The U.S. Army Physical Disability Case Processing System provides data for each case evaluated for a disability discharge since 1980. Of particular interest to this study were the disability determinations that were recommended by the Physical Evaluation Board. The options available to the board included: fit for duty; permanent disability without benefit; permanent disability with benefit; placed on temporary disability; retained on temporary disability; or to be determined by the U.S. Army Physical Disability Agency.

Although an individual may have been evaluated for disability determination on more than one occasion (e.g., if they were either placed on temporary disability), their first occurrence in the disability database was used to represent the outcome from the Physical Evaluation Board. In using the first disability record to define an event, a minimum degree of impairment is required to have existed.

Persons were assigned a temporary disability for a condition that had not yet stabilized. Frequently, they went on to receive a permanent disability status. But even among those who were later found fit for duty, they had been off work for significant lengths of time and, therefore, were included in the study as "disability" cases.

Health Risk Appraisal (HRA): The HRA is a self-administered survey of health practices and behaviors and is based on questions first developed as part of the Behavioral Risk Factor Surveys (Eddington and Yen, 1994). These Behavioral Risk Factor Surveys have been conducted by states for the Centers for Disease Control and Prevention for many years and are widely accepted as providing important information regarding lifestyles and prevention practices (Frazier et al., 1992; Siegel et al., 1993). HRA data were available in electronic format for the years 1991-1997, with approximately 140,000 respondents surveyed each year of the approximately 500,000 active duty Army personnel. Army personnel are administered the HRA in the following situations: in-processing to new work assignments (37%); periodic physical examination (34%); pre-physical fitness test (1%); occupational health program (4%); walk-in health clinic visit (4%); or other reason (20%) (Bell, unpublished data). The study enrollment requirement that subjects have completed the HRA limits the size of the cohort and insures that information on covariates will be available. Potential biases and validation issues are discussed in Section 5.2.1 Sources of Bias and Section 5.2.2 Limitations.

The value of the HRA lies in its inclusion of behavioral characteristics, such as tobacco use, which has been shown to be associated with low back injury and disability (Sacks and Nelson, 1994; Kwiatkowski et al., 1996; Amoroso et al., 1996; Lincoln et al., in progress). Smoking status was determined based on the survey response as 1) Never Smoker, 2) Former Smoker, 3) Current (Light) Smoker, and 4) Current (Heavy) Smoker. Heavy Smokers were defined as personnel who reported smoking at least 1 pack of cigarettes a day, on average (Kroutil et al., 1994). Although smoking status may be considered a time-dependent variable, the status reported at the first survey was used to represent smoking as a fixed variable. This was done because only a small proportion of subjects had taken the HRA on more than one occasion. Furthermore, efforts to assess the stability of smoking patterns yielded excellent agreement when comparing smoking practices before and after the initial hospitalization (kappa=0.74, 95% CI: 0.71, 0.77, N=1482). This high level of agreement offers confidence to the validity of the smoking status measure despite its construction as a fixed, rather than time-dependent, variable.

The HRA includes a number of variables that were useful to control for the independent role of tobacco on disability. These include alcohol use, which has been associated with both musculoskeletal injuries (Yelon et al., 1995), and tobacco use (Maletzky and Klotter, 1974). The question used to operationalize alcohol use was: "How many drinks of alcoholic beverages do you have in a typical week?"

Responses were classified into categories of 1) None, 2) Light (<6 drinks/week), 3) Moderate (6-24 drinks/week), and 4) Heavy Drinker (>24 drinks/week) based on O'Connor and Marlowe's classification in their study of low back pain in military basic trainees (1993).

The HRA includes a number of variables that have demonstrated an association with work-related low back injury and disability, such as occupational stress and job satisfaction (Williams et al., 1998; Myers et al., in press; Bigos et al., 1992). The perceived stress at work measure is based on the question "How often is your present work situation putting you under too much stress?" Job satisfaction is determined from the question "How satisfied are you with your present job assignment and unit?"

In addition, the HRA includes a series of questions that were used to compose an index of health practices that has previously been associated with smoking in a multivariate analysis (Kroutil et al., 1994). The health practices index was based on the number of conditions (0-3) that respondents satisfied from the following questions: 1) "Do you engage in non-stop aerobic activity for at least 20 minutes for 3 or more times a week?"; 2) "Do you eat at least two full meals a day, more than 5 days a week?"; and 3) "Do you usually get 6 or more hours of sleep at night?"

The final index using HRA data involves the use of height and weight responses to calculate the body mass index, a measure of body build. Body build, as well as smoking, has been shown to be an independent predictor of both low back injuries and non-low back musculoskeletal injuries in a large industrial population

(Tsai et al., 1992), back injuries among municipal workers (Myers et al., 1997), and low back disorders in a large national survey (Deyo and Bass, 1989). Other investigators have also found heavier build to be associated with higher risk of injury among military recruits (Heir and Eide, 1996; Ross and Woodward, 1994; Jones et al., 1993).

Military Occupational Specialty (MOS) and Physical Demands: An important characteristic of Army personnel is that each person has a specific occupational title, or Military Occupational Specialty (MOS). Analysis was based on the subjects' duty MOS (i.e., the job to which they were assigned), although the primary MOS (i.e., the job for which they were trained) was used if the duty MOS was missing. There are 264 principal MOSs for enlisted personnel, each with its own detailed description of job tasks, physical demand rating, and physical requirements. These are explicitly described in Army Regulation 611-201 *(Enlisted Career Management Fields and Military Occupational Specialty)* and were utilized to characterize physical demands as a surrogate for ergonomic exposures. A similar technique was recently employed in an analysis of ergonomic exposures among construction workers (Schneider et al., 1998).

Physical demands for specific MOSs were classified as Light, Medium, Moderately Heavy, Heavy, and Very Heavy (Table 2). These categories represent maximum upper body strength requirements as required for "combat conditions" performance for enlisted personnel (Department of the Army, 1994). Also, the

Department of Defense occupational coding structure was used to classify enlisted personnel into one of 10 occupational areas (DoD Directive No. 1312.1-M). Warrant officers and officers were not assigned physical demands associated with their MOS. Therefore, both the occupational areas and physical demands were used to compare cumulative risk for disability in various categories among enlisted personnel.

Table 2. U.S. Army Physical Demand Categories (Department of the Army, 1994)

	Maximum Lift Criteria (lbs)*	
Category	Frequent or Occasional	Constant
Light	20	10
Medium	50	25
Moderately heavy	80	40
Heavy	100	50
Very heavy	>100	>50

* Occasional: <20% of the time
Frequent: >20% but < 80% of the time
Constant: >80% of the time

2.5 Variables for Analysis

This study involved outcome variables for time-to-event and censoring along with an array of independent variables. Medical disability discharge represented the primary health outcome of interest. A disability indicator was assigned to "1" if the subjects was assigned a permanent or temporary disability and the indicator was assigned to "0" if subjects were not assigned a disability status. Injury severity was represented by the different injury groupings and recurrent hospitalizations. The diagnostic groupings were based on similar mechanisms of injury as discussed earlier. An indicator variable for recurrent hospitalizations for the same musculoskeletal condition was created. The indicator was represented by a "1" if two or more hospitalizations occurred, and a "0" otherwise. Table 3 lists each variable, its data source, type, and possible values.

Table 3. Variables, Data Sources, and Type

Variable	**Data Source**	**Type and Values**
	Outcomes	
Time to event	Hospitalization and Loss	continuous (months)
Disability	Disability	dichotomous (medical discharge, not)
	Individual Characteristics	
Age at initial MS hospitalization	Hospitalization	ordinal (<21, 21-25, 26-34, ≥35 years)
Sex	Personnel	categorical (male, female)
Race/ethnicity	Personnel	categorical (White, Black, Hispanic, American Indian/Alaskan Native, Asian/Pacific Islander, Other)
Education	Personnel	ordinal (no high school diploma, high school grad or GED, some college, college grad or higher)
Marital status	Personnel	categorical (single, married, no longer married, unknown)
Number of dependents	Personnel	continuous (0-15)
Pay grade	Hospitalization	ordinal (E1-3, E4-6, E7-9, W1-5, O1-3, O4-10)
	Behavioral Characteristics	
Smoking status	HRA	ordinal (never, former, current light(<1 pack/day), current heavy (≥1 pack/day))
Drinking status	HRA	ordinal (never, light, moderate, heavy)
Health practice index	HRA	ordinal (0 (low) - 3 (high))
Body build (BMI)	HRA	ordinal (sex-specific quintiles)

Occupational Characteristics		
Occupational specialty	Personnel	categorical (Enlisted: Direct combat, Electronic equipment repair, Communications & intelligence, Health care, Other technical, Support & administrative, Electrical/mechanical repair, Craftsman, Service and supply, Non-occupational; Officer)
Length of service	Hospitalization	ordinal (≤ 6 months, 7-12 months, 1-4 years, 5-10 years, > 10 years)
Occupational physical demands	Army Regulation 611-201	ordinal (light, medium, moderately heavy, heavy, very heavy)
Occupational stress index	HRA	ordinal (never, seldom, sometimes, often)
Job satisfaction	HRA	ordinal (not, somewhat, mostly, totally)
Injury Characteristics		
Diagnostic category	Hospitalization	categorical (Ganglion/cyst, bunion/toe deformities, malunion/nonunion, meniscal injury, cruciate ligament injury, collateral ligament injury, chondromalacia, non-specific back pain, disc displacement, disc degeneration
Functional grouping	Hospitalization	categorical (back, knee, overuse, other condition)
Recurrent hospitalizations	Hospitalization	dichotomous (multiple, single)
Alcohol-related comorbidity	Hospitalization	dichotomous (present, not)

2.5.1 File Construction

The file construction was achieved by collaboration with program analysts at USARIEM. Because of the confidential nature of the data, only the program analysts had access to the many files and computer resources necessary to compile the data file. Our collaboration involved identification of data elements, definition of subjects and outcomes, formatting of variables, review of file construction logic, and explanation of coding schemes.

File construction was complex because of the linkage of six data sources (Figure 3). The process began by selecting the hospitalization database containing all Army personnel and dependents for the period 1989 to 1996. The next step was to select only those cases with a principal diagnosis of interest, as defined in Table 1, and include only the initial hospitalization record for each subject so that each subject was unique. This file was then merged with the personnel file to add many demographic and occupational variables; only subjects identified as being active duty within a year of hospitalization were kept while retired persons, dependents of active duty personnel, and others were excluded. At this point, any duplicate records were removed. Following that, the file was merged with the HRA file to include key behavioral variables. Only subjects having an HRA were included, with the HRA record occurring closest to the initial hospitalization selected if more than one HRA record existed for an individual. Next, the file was merged with the disability file to add outcomes of disability evaluations, if any. The file was then merged with the loss file to ascertain the date the subject may have left the Army, thereby providing information on follow-up time and reason for leaving. If the subject did not leave the Army by the end of the study period, follow-up time was calculated through December 31, 1997. Flags were then added to the file based on the presence of an alcohol-related diagnosis or a recurrent admission for the same 4 or 5 digit principal diagnosis code as in the initial admission of interest. This was done using the master hospitalization file for 1989 to 1996 to include the presence of such diagnoses at any point during the study period. Diagnoses considered to be alcohol-related were derived from those used by the National Institute on Alcohol Abuse and Alcoholism hospital surveillance system (Fe Caces et al., 1997) and are presented in Table 4.

Next the identifying social security numbers were removed to maintain confidentiality and generic unique identifiers were added. The data file was then sent from USARIEM, and MOS and physical demand variables were added based on a summary file provided by the U.S. Army Personnel Command. To maintain a cleaner case definition, subjects were removed if they had been hospitalized for the same 4 or 5 digit principal diagnosis code prior to 1989. In addition, 27 cases that had been evaluated for disability prior to their "initial" hospitalization were identified and removed. Those remaining subjects (N=15,268) constituted the study population for the first analytic manuscript on natural history and risk factors of musculoskeletal conditions resulting in disability. Those subjects with missing data on cigarette smoking were then removed for the second paper looking specifically at the effect of smoking on musculoskeletal-related disability (N=15,120).

Figure 3. File Construction

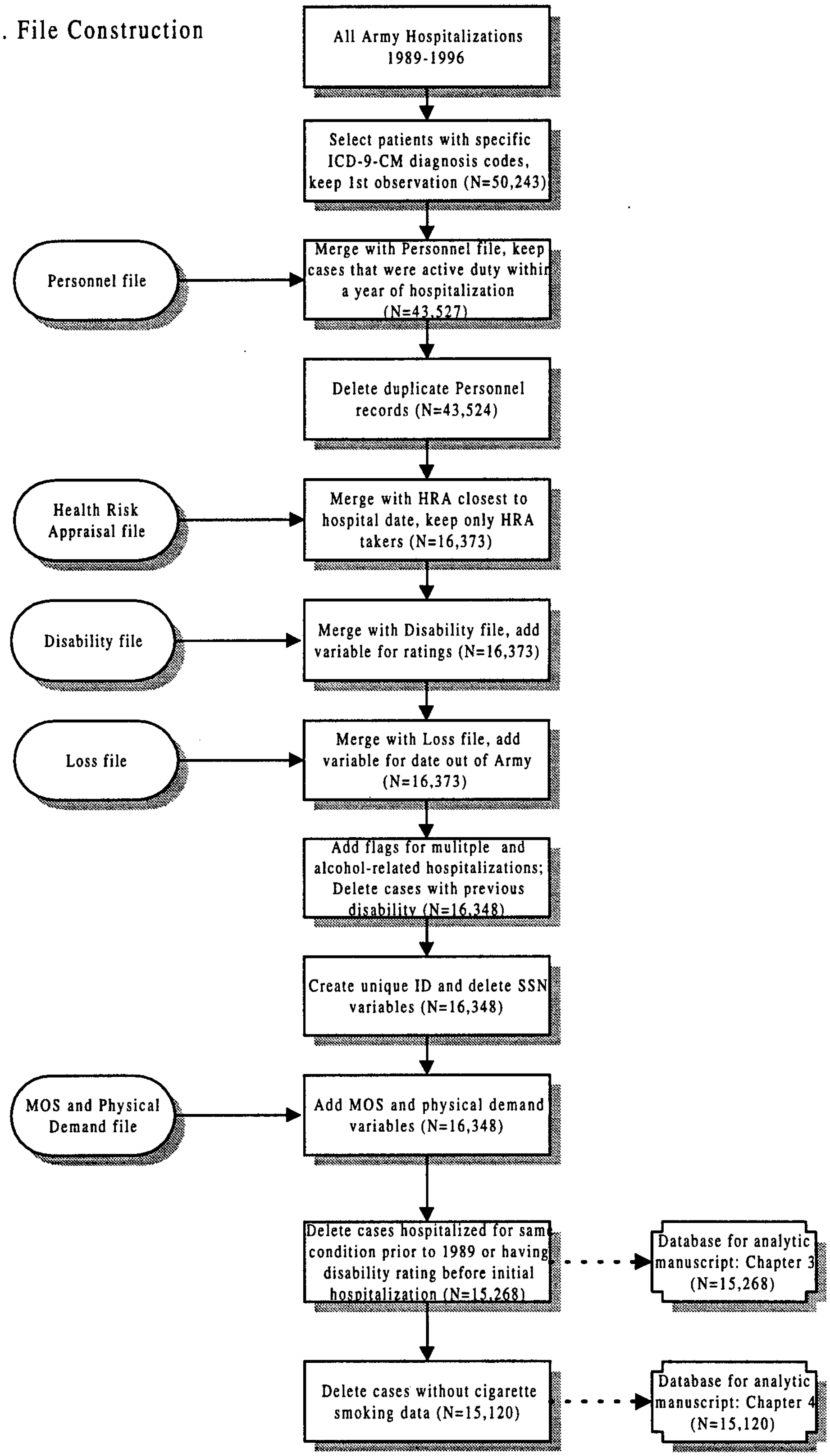


Table 4. Definition of Alcohol-Related Diagnoses (Fe Caces et al., 1997)

Category	Classification in ICD-9-CM	
Alcoholic psychoses	291.0	Alcohol withdrawal delirium
	291.1	Alcohol amnestic syndrome
	291.2	Other alcoholic dementia
	291.3	Alcohol withdrawal hallucinosis
	291.4	Idiosyncratic alcohol intoxication
	291.5	Alcoholic jealousy
	291.8	Other specified alcoholic intoxication
	291.9	Unspecified alcoholic psychosis
Alcohol dependence syndrome	265.2	Pellagra
	303.0	Acute alcohol intoxication
	303.9	Other and unspecified alcohol dependence
	357.5	Alcoholic polyneuropathy
	425.5	Alcoholic cardiomyopathy
	535.3	Alcoholic gastritis
Nondependent abuse of alcohol	305.0	Alcohol abuse
Chronic liver disease and cirrhosis:	571.0	Alcoholic fatty liver
	571.1	Acute alcoholic hepatitis
	571.2	Alcoholic cirrhosis of liver
	571.3	Alcoholic liver damage, unspecified
	571.4	Chronic hepatitis
	571.6	Biliary cirrhosis
	571.8	Other chronic nonalcoholic liver disease
	572.3	Portal hypertension
	571.5	Cirrhosis of liver without mention alcohol
	571.9	Unspecified chronic liver disease without mention of alcohol
Acute effects of alcohol	790.3	Excess blood level of alcohol
	980.0	Toxic effects of alcohol
	V70.4	Examination for medicolegal reasons
	V79.1	Alcoholism
	E860.0	Alcoholic beverages
	E860.1	Accidental poisoning by other and unspecified ethyl alcohol and its products

2.6 Analytic Plan

This section describes the various forms of analyses that were performed to assess the quality of the data overall and for the two analytic manuscripts. Sections are included on univariate analyses, measures of association between variables, sample generalizability, missing data, agreement of smoking practice over time, and sample size and power analysis.

Univariate Analyses: Analyses began with univariate statistics, including frequencies of nominal and categorical variables and distributions and measures of central tendency for continuous variables. The results were essential to determine the percentage of missing data for each variable, and decide which variable to use if there were different levels of completeness from different data sources. For example, the variable "sex" from the personnel file had 9 missing values whereas the variable "gender" from the HRA had 126 missing values, so the variable from the personnel file was used. Results also provided information on the distribution of data to facilitate the logical creation of categories and identify the presence of any outliers for further investigation.

Measures of association between variables: Pearson correlation coefficients were used to assess the association and presence of collinearity between predictor variables. Scatterplots were also used to graphically examine whether strong associations between covariates were evident.

Sample Generalizability: It is important to determine whether the characteristics of the study population are representative of both Army personnel who experienced a musculoskeletal-related hospitalization and active duty personnel in general. To investigate this, the sociodemographic characteristics were assessed for the study cohort and two comparison groups using chi-square tests (Table 5). The comparison group of injured personnel included all active duty Army personnel who were hospitalized for any of the principal diagnoses used to define the study cohort (Table 1) between 1989 and 1995. Only the first occurrence of an individual in the hospitalization file was used to be consistent with the establishment of the other groups (N=52,021). (Note: Because this group of hospitalized personnel was not linked with the personnel file, data on race/ethnicity and education level were not available for comparison.) The active duty sample was generated by random selection of the end-of-year personnel file for 5000 subjects for each of 9 years between 1989 and 1997. This sample was chosen for ease in analysis due to the huge size of the personnel files. Duplicate cases (N=955) were then eliminated, leaving 44,045 for analysis.

Results of the comparisons are presented in Table 5. Relative to all personnel with a musculoskeletal hospitalization, there is no difference in the study cohort in terms of sex ($p=0.40$), as both groups are predominantly male (85%). However, the study cohort appears to be significantly older (mean age=31.0 years, SD=7.5 versus mean age=29.5 years, SD=8.3)($p<0.0001$ from chi-square test) and has a correspondingly higher pay grade/rank ($p<0.0001$). The primary difference between these two groups is that the study cohort has definitely taken the HRA, whereas those in the hospitalized group may or may not have taken it. Having taken the HRA is likely to be correlated with length of service, because the longer an individual is in the

Army, the greater the "exposure" that he or she will have an opportunity to complete the survey. Therefore, the study cohort may be susceptible to a length of service bias that resulted in subjects being generally older and with higher pay grade/rank than those who experienced a musculoskeletal hospitalization but had not necessarily taken the HRA.

In comparison with the active duty sample, both populations were found to be predominantly male (85% for study cohort versus 87% for active duty sample), white (63% versus 62%), and well-educated (99.7% had at least a high school diploma or equivalent versus 99.5%). However, the negligible differences in the distribution of sex, race/ethnicity, and education were associated with highly significant p-values. Such significant findings are likely to be the result of very large sample sizes rather than differences in the distributions and illustrates the weakness of the statistical test.

As in the comparison with the other group, the study cohort is slightly older (mean age=31.0 years vs. 28.2 years) than the active duty sample ($p<0.0001$ from chi-square test), having only 3.6% of the population <21 years of age relative to 17.4% for the active duty sample. Similarly, there were significant differences ($p<0.0001$) in the distribution of pay grade (89% of the study cohort had an annual income of at least $30,000 (E4 or above) versus 78% of the active duty sample). As in the comparison with the hospitalization group, these differences in age and pay grade/rank are likely associated with a length of service bias. It is expected that differences in age and pay grade/rank are legitimate, while the significant differences for the other sociodemographic characteristics are less likely to be relevant.

Table 5. Comparison of Study Cohort with All Musculoskeletal Hospitalizations and Sample of Active Duty Personnel

Sociodemographic Characteristic	Study Cohort (N=15,268)		MS Hosp.1989-95 (N=52,021)		Chi-square: MS Hosp. vs. Study Cohort	Active Duty Sample (N=44,045)		Chi-square: Active Duty vs. Study Cohort
	N	%	N	%		N	%	
Sex								
Male	13,013	85.2	44,505	85.6	0.7	38,342	87.1	34.2
Female	2246	14.7	7516	14.4	(p=0.40)	5654	12.8	(p<0.0001)
Age								
<21	547	3.6	6515	12.6	1094.6	7645	17.4	2543.8
21-25	3955	26.0	13,980	26.9	(p<0.0001)	13,241	30.1	(p<0.0001)
26-34	5751	37.7	17,182	33.1		14,424	32.7	
35+	4987	32.7	14,223	27.4		8645	19.6	
Pay grade/rank								
E1-E3	1706	11.2	10,934	21.3	873.0	9732	22.1	1562.0
E4-E6	8702	57.0	27,709	53.9	(p<0.0001)	22,853	51.9	(p<0.0001)
E7-E9	2095	13.7	6186	12.0		4693	10.7	
W1-W5	446	2.9	1120	2.2		1061	2.4	
O1-O3	1266	8.3	3091	6.0		1513	3.4	
O4-O10	974	6.4	2395	4.6		4178	9.5	
Race/ethnicity								
White	9603	62.9		N/A		27,134	61.6	62.0
Black	4375	28.7				12,267	27.9	(p<0.0001)
Hispanic	603	3.9				2211	5.0	
American Indian/Alaskan Native	87	0.6				264	0.6	
Asian/Pacific Islander	219	1.4				916	2.1	
Other	371	2.4				1207	2.8	
Education level								
No H.S. diploma	47	0.3		N/A		199	0.5	175.9
HS grad/GED	11,258	73.7				33,222	75.5	(p<0.0001)
Some college	1017	6.7				2388	5.4	
College degree	2721	17.8				6907	15.7	
Unknown	220	1.4				1311	3.0	

N/A: Race/ethnicity and Education level are either coded differently or not available in the hospitalization file, so comparisons between the group with musculoskeletal hospitalizations and study cohort cannot be made.

Missing Data: The degree of missing data was identified for each variable. Information on missing values for 17 of the primary covariates is illustrated in Table 6. Generally, the rate of missing data in military data was very low. There were two variables with substantial proportions of missing values: physical demands (40.5%) and job satisfaction (19.7%). Physical demands were available for all enlisted personnel except 8.7%, but were not available for officers or warrant officers. The only other variable missing more than 3.0% of values was job satisfaction, which may be considered a sensitive question for an employer to ask its employees. Perhaps subjects were concerned about the ramifications of their response in terms of future assignments and therefore did not answer the question. Efforts to impute missing data during statistical analyses were not successful. Therefore, those cases with missing data were excluded from each statistical model.

Table 6. Missing values for covariates

Covariate	Number Missing	Percent Missing
Sex	9	0.1
Age group	0	0.0
Race/ethnicity	0	0.0
Education level	225	1.5
Pay grade/rank	79	0.5
Physical demand	6187	40.5*
Work stress	459	3.0
Job satisfaction	3014	19.7
Length of service	33	0.2
Diagnostic category	0	0.0
Alcohol use	395	2.6
Body mass index	206	1.3
Cigarette smoking	148	1.0
Number of dependents	46	0.3
Marital status	0	0.0
Recurrent hospitalization	0	0.0
Occupational specialty	0	0.0

* not available for warrant officers, officers, and 8.7% of enlisted personnel

Agreement of Smoking Practice Over Time: The HRA data regarding behaviors (e.g., smoking practice) may not necessarily be consistent at the times of hospitalization, rehabilitation, and determination of disability. In order to assess the likelihood that levels of the primary risk factor, cigarette smoking, may change over time, a sub-analysis was performed using the kappa measure of agreement for smoking history among those subjects who have completed the HRA prior to and following the initial musculoskeletal hospitalization (N=1452). Results indicate very good agreement (kappa=0.74, 95% CI: 0.71, 0.77) between first and last HRAs in regard to smoking status (e.g., nonsmoker, former, or current) (Table 7). This result suggests that smoking practice remained stable over the course of several years (mean = 37 months, SD = 42 months) for this cohort and was not affected by their hospitalization. Among subjects who were current smokers at both their first and last HRAs, the mean difference in number of cigarettes smoked per day was an increase of 0.89 (2-sided p-value = 0.035), from 15.12 to 16.01.

Table 7. Cigarette Smoking Status for Multiple HRA Takers

		Smoking Status at First HRA			
		Never	Former	Current	Total
Smoking Status at Last HRA	Never	714	51	8	773
	Former	40	176	61	277
	Current	18	47	337	402
	Total	772	274	406	1452

<u>Sample Size and Power Analysis:</u> Sample size and power calculations were based on the methodology illustrated by Collett (1994) for a survival study. Calculations were based on the difference in survival times between the two groups that represent the primary risk factor in this investigation, smokers (S), who represent 38.1% of Army personnel (Bray et al., 1992), and nonsmokers (NS). Assuming a proportional hazards model for the survival times (i.e., time to disability following initial

musculoskeletal hospitalization), the hazard of disability at time t for a subject who smokes, $h_S(t)$, can be written as $h_S(t) = \psi h_{NS}(t)$, where ψ is the unknown hazard ratio and $h_{NS}(t)$ is the disability hazard for nonsmokers. The reference log-hazard ratio is $\theta_R = \ln \psi_R$ and indicates no difference between the two groups if equal to zero, longer "survival" among smokers if θ_R is negative and longer "survival" among nonsmokers if θ_R is positive.

The value of θ_R is selected on the basis of a number of factors, including the power ($1 - \beta$) of the hypothesis test ($H_0: \theta_R = 0$), the significance level (α), the difference between the disability rates (Δ), and the ratio of disability rates (*RR*) between the smokers and nonsmokers. Table 8 illustrates how the two groups may be detected to be different depending on levels of significance, power, and disability discharge rates across the various diagnostic categories.

Sample size calculations were based on a preliminary dataset created by USARIEM that was nearly identical to that used in the actual study. Overall, there were 16,084 observations (persons hospitalized for conditions of interest) that resulted in 2190 failures (disability discharges), for a 14% estimated failure rate. For the overall study population, differences between smokers and nonsmokers were detectable at a 2% differential in failure rate and a relative risk of 1.15 with a 0.01 significance level and 80% power. The ability to detect such a small difference is desirable, and illustrates the benefit of a large study population. For the individual diagnostic categories, there was a much wider range of rate differentials and relative risks that could be detected. For example, Carpal and Cubital Tunnel Syndromes had relatively few subjects available (N=620). Therefore, the difference in disability rates (Δ=7%), relative risk (RR=2.0), significance level (α=0.05) and type II error (β=0.2) for this category was larger than for the category of Meniscal Injuries (N=3942, Δ=4%, RR=1.4, α=0.01, β=0.2) in order to achieve statistical significance.

For Cruciate Ligament Injuries (N=2478) as well as Meniscal Injuries, differences could be detectable at the α=0.01 level while for the other categories differences could be detectable at the α=0.05 level. Detectable differences in disability rates (Δ) varied from 4% (Bunion, Ganglion and Cyst) to 21% (Disc Degeneration) while relative risks (RR) varied from 1.4 (Meniscal Injury, Cruciate ligament Injury, and Disc Displacement) to 2.3 (Ganglion and Cyst). These values depended largely on the overall failure (disability) rate. To illustrate this, the category of Disc Degeneration had the fewest subjects (N=154) but the highest failure rate (29% had a disability discharge), resulting in decreased power to detect a difference of 21% between smokers and nonsmokers. This was unusual and virtually all other diagnostic categories demonstrated statistical difference at very respectable levels of power, significance, and rate differentials.

Table 8. Summary of Sample Size Requirements

Diagnostic Category	Estimate of observations	Estimate of failures	Risk of failure (overall)	Required failures (d)	Required observations (n)	Outcomes detectable		Parameters to determine sample size				
						Δ	RR	α	β	c(α,β)*	% NS	% S
A. Carpal and cubital tunnel syndromes	620	69	0.11	61	553	.07	2.0	.05	0.2	7.85	0.07	0.14
B. Meniscal injury	3942	450	0.11	408	3579	.04	1.4	.01	0.2	14.88	0.09	0.13
C. Chondromalacia	955	166	0.17	164	943	.07	1.5	.05	0.2	7.85	0.14	0.21
D. Collateral ligament injury	581	58	0.10	50	497	.07	2.2	.05	0.2	7.85	0.06	0.13
E. Cruciate ligament injury	2378	403	0.17	317	1871	.06	1.4	.01	0.2	11.68	0.14	0.20
F. Non-specific back pain	802	184	0.23	154	670	.09	1.5	.05	0.2	7.85	0.18	0.27
G. Displacement of intervertebral disc	1773	410	0.23	344	1487	.07	1.4	.05	0.2	10.51	0.19	0.26
H. Degeneration and other disc disorders	154	45	0.29	39	135	.21	2.2	.05	0.2	7.85	0.18	0.39
J. Synovitis and tenosynovitis	814	85	0.10	77	737	.06	1.8	.05	0.2	7.85	0.07	0.13
K. Bunion and deformities of toe	1547	90	0.06	64	1104	.04	2.0	.05	0.2	10.51	0.04	0.08
L. Ganglion and cyst of synovium, tendon, and bursa	1349	61	0.05	58	1286	.04	2.3	.05	0.2	10.51	0.03	0.07
M. Malunion and nonunion of fracture	796	129	0.16	105	651	.08	1.7	.05	0.2	7.85	0.12	0.20
N. Rotator cuff injury	371	39	0.11	35	330	.09	2.5	.05	0.2	7.85	0.06	0.15
Total	16084	2190	0.14	2040	14476	.02	1.15	.01	0.2	11.68	0.13	0.15

$d = c(\alpha,\beta)/(\pi_{NS}\pi_S\ \theta_R^2)$, where $\pi_{NS} = 0.6$ (proportion of nonsmokers), $\pi_s = 0.4$ (proportion of smokers)

$n = d / P(\text{failure})$

% NS: % of nonsmokers discharged due to disability

% S: % of smokers discharged due to disability

$\Delta = \%S - \%NS$

$RR = \%S / \%NS$

$c(\alpha,\beta) = (z_{\alpha/2} + z_{\beta})^2$

Strategy for Chapter 3: The initial analysis for the natural history and risk factor manuscript described the distribution of demographic (sex, age group, race/ethnicity, education, pay grade/rank, marital status, number of dependents), occupational (occupational specialty area, physical demand, work stress, job satisfaction, length of service), behavioral (cigarette smoking, alcohol use, health practices index), and clinical (diagnostic category, body mass index) factors among the entire study cohort. Following that, distributions across the same factors were created among those subjects who received a medical discharge for disability. From these two distributions, crude disability rates were calculated to determine the number of disability discharges per 100 persons admitted to hospital. These unadjusted rates offered an indication of the variability of disability rates within a specific factor.

The Kaplan-Meier method was used to estimate the hazard function and cumulative survival for each level within the factors presented above. Analysis of the 13 diagnostic groups included survival curves to demonstrate relative differences in risk of disability. In addition, Kaplan-Meier estimates were used to obtain the proportion of subjects that received a disability discharge at 6 months, 12 months, and 5 years after initial hospitalization, which provided an indication of the natural history of each diagnostic category. By comparing the risk across diagnostic categories at specific points in time, a qualitative measure of severity was presented for each condition relative to the others.

Log-rank tests for equality were used to evaluate whether differences in the risk of disability discharge exist within different categories of factors. For those factors that were ordinal, a log-rank test for trend was used to investigate whether there was a linear trend between the factor and the risk of disability discharge.

Cox proportional hazards models were then created for the four functional groupings (back, knee, overuse, and other musculoskeletal conditions) for both women and men. Separate models were created for each functional grouping to address the different mechanisms that might be associated with different types of injuries. Similarly, gender-specific models assessed how different mechanisms might affect women and men, and avoid the domination of those factors that had a greater association with men, who constituted 85% of the study population. The models were used to assess the relative hazards of various factor levels, while adjusting for other variables included in the model (Collett, 1994).

Strategy for Chapter 4: The format for the manuscript analyzing the effect of cigarette smoking on musculoskeletal-related disability is patterned largely on the study examining occupational risks associated with smoking by Ryan et al. (1992). The initial analysis examined the distribution of covariates among smoking levels using Pearson chi-square tests to identify significant differences. Characteristics assessed included sample size, average follow-up time, sex, mean age, age group, race/ethnicity, education level, pay grade/rank, occupational specialty, physical demand, work stress, job satisfaction, length of service, and diagnostic category.

The analysis continued with the distribution of the outcome (the five-year cumulative risk of disability discharge) across smoking levels for all 13 diagnostic categories and in total. A log-rank test for trend was performed to indicate the likelihood of a linear association between increasing smoking level and disability for each of the diagnostic categories. Kaplan-Meier survival curves were generated to illustrate differences associated with various levels of smoking.

The analysis followed by constructing Cox proportional hazards models to assess the role of smoking on disability discharge for each diagnostic category and in total, while adjusting for other variables. The models permitted the comparison of relative hazards among former, light, and heavy smokers to nonsmokers, the reference group.

The concluding part of the analysis assessed the attributable risk of developing disability due to smoking among subjects with meniscal injuries. The attributable risk was examined in terms of both current smokers and the entire study cohort, except for former smokers.

2.7 Statistical Techniques

This section describes the survival analyses that were performed in this study, which were essentially Kaplan-Meier estimates of survival, log-rank tests for equality and for trend, and Cox proportional hazards regressions. Analyses were performed using the Statistical Package for the Social Sciences (SPSS)™ for Windows, Release 7.5.2 (Chicago, IL).

Rationale for use of survival analysis: Survival analyses are techniques used for the analysis of time-to-event data and measures the risk of an event over time (Katz and Hauck, 1993). By focusing on the rate of the event rather than a simple proportion (i.e., cumulative risk of an event over a specified length of time), survival analysis differs from other analytic techniques, such as logistic regression. The primary advantages of using survival analyses are that they provide estimates of risk throughout the entire study period and accommodate variable lengths of follow-up time (Katz and Hauck, 1993). In addition, survival analysis makes use of the time contributed by each subject rather than discarding the experience among those subjects who did not experience the event of interest (i.e., were "censored"). The ability to allow all subjects to contribute their individual amounts of person-time is the most efficient use of available information.

A fundamental assumption of survival analysis is that censoring is uninformative (i.e., independent of the hazard rate). Applied to this study, those subjects who were censored at the end of data collection (December 31, 1997) are assumed to have the same risk of disability discharge as those subjects who were not censored.

Survival analysis techniques basically enable researchers to perform three tasks: 1) to estimate the cumulative survival function; 2) to compare the survival curves among different groups to determine significant differences; and 3) to assess the effects of some covariates while adjusting for others. All of these functions were primary goals of this study.

<u>Kaplan-Meier estimates:</u> The Kaplan-Meier estimates of survival time are based on the product limit of the life table with time intervals defined by each event. Survival curves are graphical representations of the cumulative proportion of subjects who do not experience the event at each time an event occurred (Katz and Hauck, 1993). The curves are based on the probability of survival at different points in time. They are useful to identify periods of greatest risk, as represented by the steepest slopes on the curve, and to illustrate the relative experiences of two or more groups.

Survival curves in Chapter 3 illustrate the risk of disability discharge among diagnostic categories. Kaplan-Meier estimates were used to create a summary figure comparing the risks among all diagnostic categories at 6 months, 12 months, and 5 years. In Chapter 4, survival curves illustrate differences in risk among levels of cigarette smoking over time.

<u>Log-rank tests:</u> The log-rank test compares whether the survival curves of two or more groups are significantly different from one another in time of outcome (Katz and Hauck, 1993). These statistics compare the entire curves rather than determining whether differences exist at a specific point in time. It is an appropriate test, assuming that the estimated survivor functions do not cross. The log-rank test gives equal weight to all events occurring throughout the study, and is considered to be more powerful than similar tests, such as the Wilcoxon test, when the hazard at any given time for an individual in one group is proportional to the hazard at that time for a similar individual in another group (Collett, 1994). If there were significant

differences in survival among the levels of a factor, a test statistic using a chi-squared distribution produced a small p-value, indicating that the null hypothesis (the survival across all levels was equivalent, H_0: $S_A(t) = S_B(t) = S_C(t)$..., for all event times) was rejected (Collett, 1994).

For each ordinal or continuous factor, a log-rank test for trend was performed to examine the presence of a linear association between increasing levels of a factor and the risk of disability. To give an example of one such ordinal factor, I assumed that smoking exposure levels (nonsmoker, former smoker, light smoker, and heavy smoker) were equally spaced and may be associated with a linear increase in risk of disability. The hypothesis test assumed that the slope of a line (β) representing the association between smoking level and survival was zero. A small p-value indicated that the null hypothesis (H_0: $\beta = 0$) should be rejected and provided evidence of a linear trend and dose-response relationship across smoking levels (Collett, 1994).

<u>Proportional hazards regression:</u> Proportional hazards regressions were used to evaluate the rate of disability discharge, to accommodate variable lengths of follow-up, and to assess the effect of multiple covariates on the rate of disability discharge (Katz and Hauck, 1993). The model is defined in terms of the hazard, or the probability that a subject will experience a disability discharge in the next unit of time, given that the subjects have not yet experienced the outcome (Katz and Hauck, 1993). Hazard can also be theoretically defined as the instantaneous risk of disability discharge.

Simplistically, it is assumed that the hazard in those subjects exposed to a specific risk factor [$h_1(t)$] is a multiple [$e^{\beta x}$] of some underlying hazard function [$h_0(t)$]:

$$h_1(t) = h_0(t) * e^{\beta x} .$$

According to this model, the relative hazard is defined by:

$$h_1(t) / h_0(t) = e^{\beta x} ,$$

and the risk factor [βx] is the logarithm of the relative hazard:

$$\log (h_1(t) / h_0(t)) = \beta x .$$

Therefore, the hazard function [$h_1(t)$] is composed of a nonparametric [$h_0(t)$] and a parametric [$e^{\beta x}$] component, and is termed "semiparametric". However, because the underlying hazard function [$h_0(t)$] is eliminated in the calculation of regression coefficients, it is not necessary to specify or estimate it, thereby simplifying computation.

Fitting the model: The coefficients in the proportional hazards model are estimated using the method of maximum likelihood (Collett, 1994; Cox, 1972). The rationale is to identify the probability that an individual with specific characteristics experiences an event at time t_i given that one event occurred among subjects at risk (i.e., those in the risk set) at that time. The likelihood function [L] is the product of those probabilities taken at the occurrence of each event. The coefficients are obtained by maximizing the value of L, the likelihood function, which involves calculating the logarithm of L, taking the first derivative, setting it equal to zero, and solving for the coefficients. Because the likelihood function does not make direct use of the actual censored and uncensored survival times, it is considered a "partial likelihood function".

Proportional hazards coefficients: The coefficients produced by the partial likelihood function are a measure of the association between a covariate and rate of disability discharge after controlling for other covariates (Katz and Hauck, 1993). The coefficients can be either positive, indicating an increasing hazard as the covariate increases, or negative, indicating a decreasing hazard as the covariate increases. The effect of a one-unit change in the covariate on the hazard is estimated by exponentiating the coefficient [e^{β}], resulting in the "relative hazard". The relative hazard presents a measure of the relative difference in disability rates between each level of a covariate and is assumed to be constant across the range of values for that covariate. In addition, confidence intervals for relative hazards can be calculated based on the coefficient and standard error for each covariate. The confidence interval offers a measure of the precision of the estimate and the interval of plausible values (Katz and Hauck, 1993).

Construction of models: In Chapter 3, gender-specific models for each of the functional groups (back, knee, overuse, and other musculoskeletal conditions) were created for a total of eight models. The intent of the proportional hazards regressions was to identify which covariates were significantly associated with disability and the magnitude of the association.

In Chapter 4, separate models were created for each of the 13 diagnostic categories. The intent of these regressions was slightly different, as the effect of smoking level on disability was identified while adjusting for other covariates.

Variables included in the model for Chapter 3: All variables were initially included for each model. These were: age group, race/ethnicity, education level, marital status, number of dependents, pay grade, length of service, occupational category, physical demands, job satisfaction, work stress, diagnostic category, body mass index (quintile), recurrent musculoskeletal hospitalization, alcohol use, alcohol-related comorbidity, cigarette smoking status, and health practices index. Although sex was not found to be significant in log-rank testing, models were stratified by sex because of the theoretical argument that women and men may develop a disability as a result of different mechanisms, and that the majority of men composing the cohort would dilute the effects of factors associated with women and disability.

The effect of potentially relevant interactions was explored to determine whether their inclusion improved the fit of the models. Many of the interactions (e.g., cigarette smoking by alcohol consumption, cigarette smoking by work stress, cigarette smoking by physical demands, cigarette smoking by job satisfaction, work stress by job satisfaction) were found to be statistically insignificant. For other interactions (e.g., age group by length of service, work stress by physical demands), inclusion of both the interaction term and main effect terms, as required by the hierarchic principle

(Collett, 1994), resulted in inappropriate estimates stemming from the collinearity of the factors. In effect, no interactions were identified. The absence of interactions is supported by the finding in Rothenbacher et al. (1998) that did not identify significant interactions for their study of early retirement due to physical disability.

The models were assessed with both forward and backward conditional stepwise procedures. Similar results were obtained from the two methods in terms of level of significance and magnitude of each covariate; results obtained from the forward stepwise procedure are included in the manuscripts. The p-value for entry in the model was 0.10 and the p-value for exclusion from the model was 0.20. These were different than the standard values of 0.05 and 0.10, respectively, and were selected to ensure that variables of importance would be considered if they were at least marginally significant and also so that potential confounders would not be removed from the analysis prematurely (Hosmer and Lemeshow, 1990).

The variable with the smallest p-value for its score statistic (testing that its coefficient is equal to zero) was entered first if it met the criteria for entry. The log-likelihood test was performed to determine any improvement in the model with the addition of the first covariate. This process was repeated until no further covariates improved the fit of the model at the $p < 0.10$ significance level.

Because of missing values for various covariates, the process of including all covariates had the potential to significantly limit the number of subjects available for analysis. After first running the forward-stepping procedure with all the possible covariates, a regression was repeated, this time limiting the covariates to those that were initially found to be significant. This typically resulted in more subjects available for analysis and greater power to detect associations, especially if the covariates physical demands or job satisfaction were not found to be significant. (See the discussion of Missing Data in Section 2.6 for further details.)

<u>Variables included in the model for Chapter 4:</u> Because the intent of this manuscript was to identify the effect of smoking among each of the diagnostic categories, rather than to identify only those covariates with significant associations to the outcome, a forced entry method was used. This was decided following the analysis for Chapter 3, where cigarette smoking was only found to be significant among males with knee conditions. Recognizing that cigarette smoking was likely not to be a significant predictor for each diagnostic category, the forced entry method was used in models that included any of those covariates identified as being significant in the eight regression models used in Chapter 3. In addition to cigarette smoking, the covariates initially entered in the model included: age group, sex, race/ethnicity, education, pay grade/rank, length of service, physical demands, occupational specialty, work stress, and job satisfaction. However, large proportions of subjects without values for physical demand (40.5% of study population) or job satisfaction (19.7%) and the subsequent effect to limit sample size forced the removal of those covariates from later regressions. In addition, occupational specialty had to be removed from the models because it was found to be collinear with pay grade/rank. Therefore, the effect of smoking does not include adjustment for physical demands, job satisfaction,

or occupational specialty.

In addition to regressions for each of the diagnostic categories, a model was run for all categories combined. Recognizing that smoking was found to be highly significant for only one of the diagnostic categories (meniscal injury), a sensitivity analysis was performed by repeating the regression for all categories combined except meniscal injury.

Proportionality assumptions: A fundamental assumption inherent to the proportional hazards model is that the survival time among individuals in different levels of a covariate are proportional to each other and that these proportions are stable across the range of follow-up time. One technique to examine the validity of this assumption is to use a log minus log (LML) plot of the survival function over time (Steinberg, 1997). For the proportionality assumption to be satisfied, the curves generated by the log minus log plot should be parallel. LML plots for the covariates cigarette smoking and job satisfaction for a model of male subjects with knee conditions (used in Chapter 3) are presented to illustrate the validity of the proportionality assumption (Figures 4 and 5).

Attributable risk calculations: The attributable risk is defined as the "proportionate excess risk of disease that is associated with exposure to a risk factor" (Kahn and Sempos, 1989) and was calculated based on both the magnitude of the risk factor and the proportion of the population exposed to the factor (ibid.). The initial estimate assessed the proportion of the disability incidence rate following hospitalization *among current smokers* due to the association with smoking. This was calculated based on the equation

$AR = (I_S - I_{NS}) / I_S = (RR - 1) / RR$ where the following terms are defined:

AR attributable risk

I_S crude incidence rate for disability after hospitalization among current smokers

I_{NS} crude incidence rate for disability after hospitalization among nonsmokers

RR relative risk as defined for a prospective study (ibid.).

The second estimate gave the proportion of disability following hospitalization *in the study population*, excluding former smokers, associated with current cigarette smoking. This was based on the equation

$AR = P(RR-1) / [1+P(RR-1)]$ where P is the proportion of current smokers.

In addition, the 95% confidence interval was calculated for the population attributable risk according to the variance formula for prospective data provided by Kahn and Sempos (p.78).

Figure 4. Log-minus-log plot of smoking levels for males with knee conditions

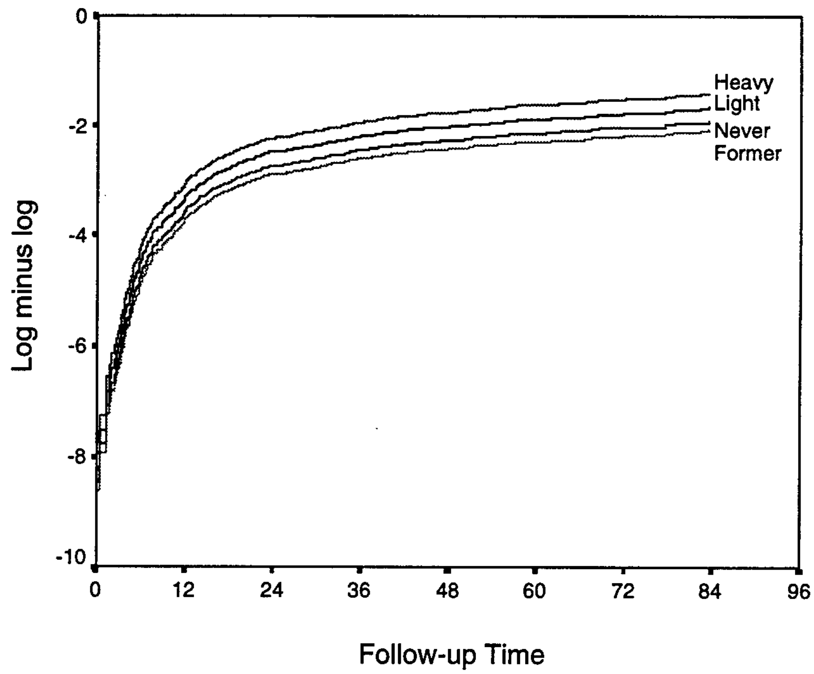
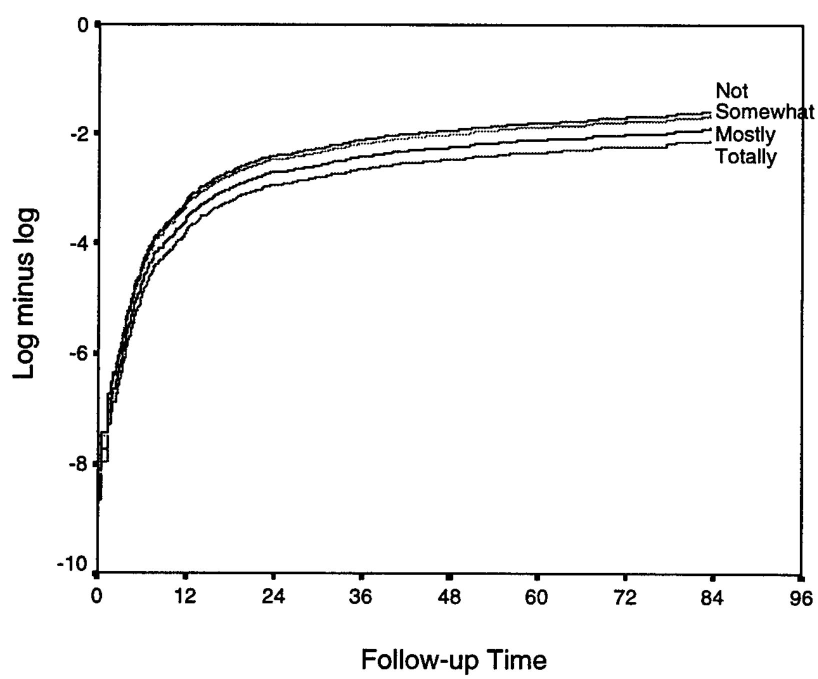


Figure 5. Log-minus-log plot of job satisfaction for males with knee conditions



2.8 Summary

The purpose of this research was to investigate risk factors for the development of physical disability following the occurrence of a musculoskeletal disorder that results in hospitalization. The natural history of various diagnostic categories was described from the point of initial hospitalization to the outcome of medical discharge for disability from the service. In addition, factors that may contribute to this outcome were studied. In particular, the role of smoking was investigated among each of the diagnostic categories to determine whether there was variation in smoking's effect and which diagnoses were more susceptible to those effects.

Identification of risk factors is the first step in prevention of poor health outcomes, raising questions about causal relationships (Hubert et al., 1993). This is followed by the development of interventions focusing on modifiable risk factors, and then an extension of the model to other study populations and environments. It is hoped that the model and methodology used in this study will offer insight to the development of disability and policies that may help to minimize or even prevent it.

Chapter 3

The Natural History and Risk Factors of Musculoskeletal Conditions Resulting in Disability Among U.S. Army Personnel

Andrew E. Lincoln, MS [1]
Gordon S. Smith, MB, ChB, MPH [1]
Paul J. Amoroso, MD, MPH [2]
Nicole S. Bell, ScD [3]

[1] Center for Injury Research and Policy, Department of Health Policy and Management The Johns Hopkins University School of Public Health, Baltimore, MD

[2] U.S. Army Research Institute of Environmental Medicine, Natick, MA

[3] Social Sectors Development Strategies, Inc., Natick, MA

Address for correspondence and reprint requests:
Andrew E. Lincoln, M.S.
The Johns Hopkins Center for Injury Research and Policy
624 N. Broadway
Baltimore, MD 21205
(410)614-4023, fax (410)614-2797
alincoln@jhsph.edu

7 Tables, 3 Figures

Key words: musculoskeletal conditions, natural history, disability, epidemiology, occupation, military

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ABSTRACT

Purpose: To describe the natural history of 13 common musculoskeletal conditions that required hospitalization of U.S. Army personnel and identify factors most strongly associated with subsequent development of disability resulting in discharge from the Army.

Design: A retrospective cohort design involving five linked databases was utilized to assess the roles of demographic, behavioral, psychosocial, occupational, and clinical characteristics in the development of physical disability. Subjects included 15,268 U.S. Army personnel hospitalized for common musculoskeletal conditions between the years 1989-1996 who were followed through 1997.

Results: The overall disability discharge rate was 9.5/100 initial hospitalizations for musculoskeletal conditions. Back conditions had the greatest five year cumulative risk of disability following hospitalization (21%, 19%, and 17% for intervertebral disc displacement, intervertebral disc degeneration, and nonspecific low back pain, respectively). Cox proportional hazards models identified the following risk factors for disability among males: lower pay grade, musculoskeletal diagnosis, shorter length of service, older age, occupational category, lower job satisfaction, recurrent musculoskeletal hospitalizations, heavy cigarette smoking, greater work stress, and heavy physical demands. Among females, fewer covariates reached statistical significance, although lower education level was found to be predictive.

Conclusion: Musculoskeletal conditions requiring hospitalization represent a substantial risk of disability discharge from the U.S. Army. Back conditions are the

most severe and have the highest 5 year cumulative risk of disability. Demographic, behavioral, psychosocial, occupational, and clinical characteristics are associated with disability discharge. Modifiable risk factors such as job satisfaction, work stress, and smoking suggest possible targets for intervention.

INTRODUCTION

Musculoskeletal conditions are associated with the majority (51%) of diagnoses resulting in disability discharge from the U.S. Army (Feuerstein et al., 1997). However, the natural history of these conditions following their incidence is largely unknown. Despite the tremendous cost of musculoskeletal-related disability payments to veterans (lifetime costs of $485 million to newly disabled Army personnel in 1993 (Jones and Hanson, 1996) and average costs of $277,000 per permanent disability case (Department of Defense Actuary, in press), few studies have examined the course of these conditions and the risk factors that may be associated with the outcome of discharge from the service due to disability.

Several investigators have examined the roles of demographics (Berkowitz and Feuerstein, in press; MacKenzie et al., 1997; Feuerstein et al., 1997; Badley and Ibanez, 1994; Cheadle et al., 1994; Hubert et al., 1993; Lehmann et al., 1993; Volinn et al., 1991; Rissanen et al., 1990; MacKenzie et al.; 1987), physical demands (MacKenzie et al., 1997; Liira et al., 1996; Cheadle et al., 1994; Makela et al., 1993), psychosocial factors (Deyo and Tsui-Wu, 1987; Deyo and Diehl, 1988; MacKenzie et al., 1997; Badley and Ibanez, 1994; Makela et al., 1993; Hubert et al., 1993; Volinn et al., 1991; MacKenzie et al., 1987;), and employment-related factors (Williams et al., 1998; Berkowitz and Feuerstein, in press; Bigos et al., 1992; Lancourt and Kettelhut, 1992; Habeck et al., 1991; Drury, 1991) in the development of musculoskeletal-related disability, or the alternative outcome of return to work. While psychosocial factors are now recognized to play a primary role in a successful rehabilitation, few studies have the opportunity to study an array of factors that simultaneously include demographic, behavioral, occupational, and clinical features using an extended follow-up period. The aims of this study were to: 1) describe the natural history of common musculoskeletal conditions requiring hospitalization of Army personnel; and 2) given hospitalization for a musculoskeletal condition, identify those factors that are most strongly associated with disability discharge. It is important to identify which factors play significant roles in the development of physical disability so that we may distinguish which are modifiable and, therefore, amenable to intervention. Results provide scientific estimates of disability risk following hospitalization for musculoskeletal disorders in the U.S. Army and offer suggestions for successful rehabilitation management of those factors found to be most important.

METHODS

Study Design

A retrospective cohort design was used to follow U.S. Army personnel from their initial musculoskeletal-related hospitalization, which occurred between the years 1989 and 1996, through the development of physical disability, up to 1997. This design incorporated many different data sources from the U.S. Army to include 22 variables that are often considered to be potential confounders of associations between various exposures and health outcomes (Table 1).

Cohort Definition

To be included in the study, cohort subjects must have met several criteria: 1) been on active duty at the time of hospitalization; 2) been hospitalized for a specified musculoskeletal disorder or severe sprain/strain during the period 1989 to 1996 (Table 2); and 3) completed a health risk appraisal (HRA) at some point during the same time period. The goal of the study was to capture hospitalized subjects at their first admission for one or more of the diagnoses of interest. Therefore, subjects hospitalized for the same condition prior to 1989 (N=1053) or having a disability board preceding the initial musculoskeletal hospitalization (N=27) were disqualified and eliminated from the cohort. The total number of qualifying subjects remaining was 15,268.

Data Sources

Data were obtained from the Total Army Injury and Health Outcomes Database (TAIHOD), a collection of databases that was recently created primarily for injury prevention and women's health research (Amoroso et al., 1997). Unique identifiers (scrambled social security numbers) enabled us to link information across databases, in effect permitting us to track the natural history of a subject's condition. The completeness of the Army's administrative databases provides excellent follow-up with minimal loss of cohort subjects. This study was approved by The Johns Hopkins School of Hygiene and Public Health Committee on Human Research.

This study made use of four types of data: demographics, health practices, health outcomes (hospitalizations), and functional outcomes (disability ratings). Five separate databases were linked: personnel, hospitalization, health risk appraisal (HRA), disability, and loss from service. The personnel file provided information on demographic variables. The hospitalization file offered information on date of admission, diagnosis, and recurrent hospitalization. The health risk appraisal data allowed us to incorporate behavioral influences beyond the personal characteristics and occupational exposures that are commonly utilized in epidemiological studies. The disability file offered data on outcomes from disability evaluations. The loss from service file provided valuable information regarding censoring of subjects.

Diagnostic Categories

Diagnostic categories were selected based on the likelihood of well-defined clinical symptoms (e.g., cruciate ligament injury) to permit an accurate diagnosis or large enough numbers (e.g., non-specific back pain) to provide adequate statistical power (Table 2). Diagnoses included both "acute" injuries within ICD-9-CM codes 836, 840, or 844 and "chronic" conditions (710-739, 354) that represent similar clinical presentations. These 40 diagnoses in 13 categories were further classified into 4 functional groups for more detailed analyses: knee, back, overuse, and other musculoskeletal conditions. Discussions with an injury researcher with experience in coding (Gordon Smith, MD, MPH, Johns Hopkins School of Hygiene and Public Health), a practicing orthopedist (Richard Hinton, MD, MPH, MPT, MEd, Johns Hopkins School of Medicine), and a practicing physiatrist (Tamara Lauder, MD, Johns Hopkins School of Medicine) were conducted to develop the diagnostic categories and functional groupings that involve similar mechanisms of injury or healing. We decided not to examine all musculoskeletal injuries, rather we sought to focus on a group of clean diagnostic and clinical entities since the whole group of musculoskeletal conditions cover a broad range of widely discrepant disorders.

<u>Endpoint</u>

The outcome of interest, disability, is defined as having been assigned the following status at a medical evaluation board at some point between the initial hospitalization and the end of 1997: 1) permanent disability/retirement (disability rating of at least 20% or having at least 20 years of service); 2) severance without benefits (disability rating of less than 20% and having less than 20 years of services); or 3) temporary disability. Because this study was designed to document the incidence of disability following musculoskeletal hospitalization, all medical discharges for disability were included, regardless of the primary cause or condition.

Time to disability (number of months) was determined from the point of the initial musculoskeletal hospitalization until the subject was either medically discharged, discharged for other reason (e.g., honorable discharge, death), or censored because of the end of the follow-up period (Figure 1). Although an individual may have been evaluated for disability determination on more than one occasion (i.e., if they were placed on temporary disability), their first occurrence in the disability database was used to represent the outcome from the Physical Evaluation Board.

Persons were assigned a temporary disability for a condition that had not yet stabilized. Frequently, they went on to receive a permanent disability status. But even among those who were later found fit for duty, they had been off work for significant lengths of time and, therefore, were included in the study as "disability" cases.

Military Occupational Specialty (MOS) and Physical Demands

Physical demands for specific MOS were classified as Light, Medium, Moderately Heavy, Heavy, and Very Heavy (Army Regulation 611-201). These categories represent maximum upper body strength requirements as required for "combat conditions" performance for enlisted personnel (Department of the Army, 1994). Also, the Department of Defense occupational coding structure was used to classify enlisted personnel into one of 10 occupational categories (DoD Directive No. 1312.1-M, 1989).

Analysis

Sample Generalizability: It is important to determine whether the characteristics of the study population are representative of both Army personnel who experienced a musculoskeletal-related hospitalization and active duty personnel in general. To investigate this, the sociodemographic characteristics were assessed for the study cohort and two comparison groups using chi-square tests (Table 3). The comparison group of injured personnel included all active duty Army personnel who were hospitalized for any of the principal diagnoses used to define the study cohort (Table 1) between 1989 and 1995. Only the first occurrence of an individual in the hospitalization file was used to be consistent with the establishment of the other groups (N=52,021). (Note: Because this group of hospitalized personnel was not linked with the personnel file, data on race/ethnicity and education level were not available for comparison.) The active duty sample was generated by random selection of the end-of-year personnel file for 5000 subjects for each of 9 years between 1989 and 1997. This sample was chosen for ease in analysis due to the huge size of the personnel files. Duplicate cases (N=955) were then eliminated, leaving 44,045 for analysis. All analyses were performed with SPSS for Windows 7.5.2 (Chicago, IL).

Data Accuracy: The HRA data regarding behaviors (e.g., smoking practice) may not necessarily be accurate at the times of hospitalization, rehabilitation, and determination of disability. In order to assess the likelihood that one such behavior may change over time, a sub-analysis was performed using the kappa measure of agreement for smoking history among those subjects who have completed the HRA prior to and following the initial musculoskeletal hospitalization (N=1452). Results indicate very good agreement (kappa=0.74, 95% CI (0.71, 0.77)) between first and last HRAs in regard to smoking status (e.g., nonsmoker, former, current). This suggests smoking practice remained stable over several years (mean = 37 months, SD = 42 months) for this cohort. Among subjects who were current smokers at both HRAs (N=360), the mean difference in number of cigarettes smoked per day was an increase of 0.89 (2-sided p-value = 0.035).

Time-to-Disability Discharge: Kaplan-Meier estimates of cumulative survival of subjects receiving a medical disability discharge were calculated for each of the 13 diagnostic categories. These offer a natural history of the development of disability following hospitalization. Estimates of the cumulative proportion receiving a disability discharge were examined by each of the risk factors considered one at a time. The statistical significance of the association between each risk factor and the cumulative probability of disability discharge were assessed using log-rank tests for equality of factor levels and for linear trend (Collett, 1994). Comparisons were made between age groups, gender, races, pay grades, occupational specialties, physical demand levels, smoking status, alcohol use, health practices, body mass, education levels, marital status, number of dependents, length of time in service, diagnostic categories, hospitalization recurrence, sick days, alcohol-related comorbidity, job satisfaction, and work stress levels.

The Cox proportional hazards model was used to estimate the combined effect of multiple risk factors and the contribution of each factor independently (Collett, 1994). Variables were entered into the model as either nominal (gender, race/ethnicity, marital status, occupational specialty, diagnostic category), ordinal (age group, education level, pay grade/rank, gender-specific body mass index quintile, cigarette smoking status, alcohol use, MOS physical demand, length of time in service, job satisfaction, work stress, recurrent hospitalization), or continuous (health practice index, number of dependents) covariates. Interaction terms involving the variables for age group, length of service, cigarette smoking, alcohol consumption, work stress, job satisfaction, and physical demands were examined. However, none of the terms were found to be significant and were therefore not included in the models. Results provided the relative hazard of the exposure while adjusting for other covariates and assumed that the effect of any given covariate on the hazard function was constant over the study period. Gender-specific Cox proportional hazards models were created using a forward-conditional stepwise approach (p_{entry} = 0.10, $p_{removal}$ = 0.20). Plots of log minus log (survival) functions against time were used to check assumptions of proportional hazards.

RESULTS

Sample Generalizability

Results of the comparisons are presented in Table 3. Relative to all personnel with a musculoskeletal hospitalization, there was no difference in the study cohort in terms of sex (p=0.40), as both groups are predominantly male (85%). However, the study cohort appeared to be significantly older (mean age=31.0 years, SD=7.5 versus mean age=29.5 years, SD=8.3)(p<0.0001 from chi-square test) and had a correspondingly higher pay grade/rank (p<0.0001). The primary difference between these two groups was that the study cohort has definitely taken the HRA, whereas those in the hospitalized group may or may not have taken it. Having taken the HRA was likely to be correlated with length of service, because the longer an individual was in the Army, the greater the "exposure" that he or she had an opportunity to complete the survey. Therefore, the study cohort may have been susceptible to a length of service bias that resulted in subjects being generally older and of higher pay grade/rank than those who experienced a musculoskeletal hospitalization but had not necessarily taken the HRA.

In comparison with the active duty sample, both populations were found to be predominantly male (85% for study cohort versus 87% for active duty sample), white (63% versus 62%), and well-educated (99.7% had at least a high school diploma or equivalent versus 99.5%). However, the negligible differences in the distribution of sex, race/ethnicity, and education were associated with highly significant p-values. Such significant findings were likely to be the result of very large sample sizes rather than differences in the distributions and illustrates the weakness of the statistical test.

As in the comparison with the other group, the study cohort was slightly older (mean age=31.0 years vs. 28.2 years) than the active duty sample ($p<0.0001$ from chi-square test), having only 3.6% of the population <21 years of age relative to 17.4% for the active duty sample. Similarly, there were significant differences ($p<0.0001$) in the distribution of pay grade (89% of the study cohort had an annual income of at least $30,000 (E4 or above) versus 78% of the active duty sample). As in the comparison with the hospitalization group, these differences in age and pay grade/rank were likely associated with a length of service bias. It was expected that differences in age and pay grade/rank were legitimate, while the significant differences for the other sociodemographic characteristics were less likely to be relevant.

Disability Discharge Rates by Population Subgroups

Results of the bivariate analysis for the study population are presented in Tables 4 and 5. Overall, the disability discharge rate was 9.52 per 100 initial musculoskeletal hospitalizations. Differences among strata, as determined by the log-rank test for equality ($p<0.05$), included age groups, race/ethnicity, education level, pay grade, body mass index quintile, cigarette smoking status, marital status, number of dependents, occupational specialty, MOS physical demands, work stress, job satisfaction, length of service, health practices index, and within the diagnostic subgroups of knee and other conditions. (Note: Not all are shown.) Specifically, rates were highest among the following subgroups: 21-25 year olds (12.1/100) or 26-34 year olds (12.5); enlisted personnel in the lowest pay grades (E1-E3) (17.0); those in the service for ≤ 6 months (18.7) or 7-12 months (16.7); diagnosed with intervertebral disc displacement (16.7), intervertebral disc degeneration (14.6), nonspecific back pain (13.8), or chondromalacia (12.4); having multiple musculoskeletal hospitalizations (15.0); having a duty MOS of electronic equipment repair (13.3) or other technical jobs (13.6); being in a "very heavy" physically demanding occupation (12.8); often stressed at work (13.7); not satisfied with present job (13.2); heavy smokers (1+ pack/day) (12.3); heavy drinkers (> 24 drinks/week) (12.4); and single persons (11.7) or those having no dependents (11.3). Diagnoses of meniscal injury (N=300), displacement of intervertebral disc (N=268), and cruciate ligament injury (N=244) were most frequently associated with disability discharge. Log-rank tests for linear trend identified older age group, lower education level, lower pay grade, more cigarette smoking, having fewer dependents, more physically demanding job, greater work stress, lower job satisfaction, shorter length of service, recurrent hospitalizations, and fewer health practices to be at increased risk for disability discharge ($p<0.001$).

Natural History by Diagnostic Category

Survival curves for the 13 diagnostic categories provided estimates of the risk of disability discharge over an extended follow-up period. (Note: Survival curves for back conditions are shown in Figure 2 while those for knee conditions, overuse conditions, and other musculoskeletal conditions are presented in the appendix.) For many of the categories, Kaplan-Meier estimates were stable throughout 72 to 84 months of follow-up time, although some categories with relatively small numbers of subjects produced curves that are informative for only the initial 36 to 48 months. The maximum follow-up time obtainable was nine years (108 months).

A summary of the survival curves for all 13 diagnoses presents the cumulative risk of disability discharge at 6 months, 12 months, and 5 years after the initial musculoskeletal hospitalization (Figure 3). These data indicate that intervertebral disc degeneration was the most severe condition, having the highest cumulative disability at 6 months (5.7%) and 12 months (9.1%). The five year cumulative risk of disability was highest for the three back conditions: intervertebral disc displacement (20.8%), intervertebral disc degeneration (19.1%), and nonspecific back pain (16.7%).

Among the back conditions, non-specific low-back pain provided the least risk of disability discharge, particularly in comparison with intervertebral disc displacement (Figure 2). The log-rank test for equality of hazard function was marginally significant (p=0.08). During the initial 15 months, the survival curve for degeneration and other disc disorders was most severe among the back conditions, but the small number of cases beyond that point made it difficult to interpret how the longer-term survival compared with other back conditions.

Knee conditions, representing the most commonly occurring musculoskeletal condition in the study cohort (49%), illustrated distinct progressions to disability among the diagnoses (log-rank test for equality p-value<0.001). Meniscal injuries were least likely to result in disability, followed by cruciate ligament injuries and then chondromalacia, which demonstrated the most hazardous survival curve among this diagnostic group. Injuries to the collateral ligament had a survival curve nearly identical to that of cruciate ligament injuries until approximately 40 months, at which point the curve became erratic because of the small number of cases. These results indicate that a chronic condition, such as chondromalacia, is more likely to result in disability than acute knee injuries, given the physical demands associated with a military environment.

Among overuse conditions (e.g., synovitis and tenosynovitis, carpal and cubital tunnel syndrome, and rotator cuff injury), there was little difference in progression to disability (log-rank test for equality p-value = 0.90). Beyond 48 months, there was a greater hazard among those with carpal and cubital syndromes than for synovitis and tenosynovitis. Because of relatively few subjects with rotator cuff injury (N=330), the Kaplan-Meier estimate had little information beyond 32 months, when the curve approached a horizontal line.

The three diagnostic categories that compose other musculoskeletal conditions demonstrate clearly differentiated survival curves (log-rank test for equality p-value < 0.001). Ganglion/cyst conditions resulted in the least disability among all of the 13 diagnostic categories, with a cumulative risk of disability discharge of 8.8% beyond 81 months. The diagnostic category of bunion/toe deformity had a survival curve identical to that of ganglion/cyst up to 30 months, at which time it assumed an increased risk of disability. Conditions of fracture malunion/nonunion produced the greatest hazard within this group, particularly within the initial 24 months.

Prognostic Signs of Disability Discharge for Men

Proportional hazards models for each diagnostic group provided estimates of relative hazard for disability discharge (Table 6). Among back conditions, the ability to control for the effects of confounding variables identified length of service (p<0.001), diagnostic category (p=0.012), age group (p=0.014), physical demands (p=0.037), and pay grade (p=0.044) to be significantly associated with disability discharge. Personnel at highest risk included: those in the service for 1-4 years (RH=2.8, 95% CI: 1.8, 4.3) relative to those with greater than 10 years of service; 26-34 years old (RH=13.1, 95% CI: 1.8, 94.7) relative to those <21 years old; diagnosed with intervertebral disc degeneration (RH=1.9, 95% CI: 1.1, 3.6) relative to nonspecific back pain; and those of lower rank (E4-E6) (RH=1.9, 95% CI: 1.1, 3.2) relative to E7-E9. Increased physical demand was not associated with increased risk.

Significant predictors among males with knee conditions included age group ($p<0.001$), pay grade ($p<0.001$), cigarette smoking ($p<0.001$), length of service ($p=0.001$), recurrent hospitalizations ($p=0.009$), work stress ($p=0.024$), job satisfaction ($p=0.025$), physical demands ($p=0.031$), and diagnostic category ($p=0.066$). Personnel at highest risk were: 26-34 years old; lowest ranking enlisted personnel (E1-E3); heavy smokers (1+ pack/day); those with 7-12 months of service; those with one or more recurrent musculoskeletal hospitalizations; those not satisfied with their job; those in MOSs with heavy physically demands; and those diagnosed with chondromalacia. Increased work stress was not associated with increased risk.

Among overuse conditions, length of service ($p<0.001$), age group ($p=0.004$), physical demands ($p=0.044$), and work stress ($p=0.083$) were significantly associated with disability discharge. Personnel at highest risk included those who were: 35+ years old; in the service for 1-4 years; often experienced work stress; and in MOSs with heavy physical demands, although the wide confidence interval reflects the small number in the heavy classification (N=16). In addition, those in moderately heavy and very heavy MOSs appeared to be protected.

For the other musculoskeletal conditions, diagnostic category ($p<0.001$), length of service ($p=0.002$), age group ($p=0.004$), occupational category ($p=0.018$), recurrent hospitalization ($p=0.061$), and pay grade ($p=0.084$) were predictive of disability discharge. At greatest risk were those with: a diagnosis of fracture malunion or nonunion; 1-4 years of service; 35+ years old; jobs in electrical equipment repair; lowest ranking enlisted personnel (E1-E3); and having at least one recurrent musculoskeletal hospitalization.

Prognostic Signs of Disability Discharge for Women

Fewer covariates reached statistical significance in proportional hazards models for females than for males (Table 7). Predictors of disability discharge for back conditions included only diagnostic category (p=0.018) and length of service (p=0.065). Greatest risk existed for those diagnosed with intervertebral disc displacement (RH=2.4, 95% CI: 1.3, 4.4) relative to nonspecific back pain and those who had served 1-4 years (RH=2.7, 95% CI: 1.3, 5.3) relative to those with more than 10 years of service.

For females with knee conditions, education level (p<0.001), length of service (p=0.023), and job satisfaction (p=0.024) were identified as significant predictors of disability discharge. Those at highest risk were high school graduates (RH=8.8, 95% CI: 2.7, 28.7) relative to college graduates, those who have served 6 or fewer months (RH=6.3, 95% CI: 1.9, 20.9) relative to those with more than 10 years of service, and those not satisfied with their jobs (RH=1.7, 95% CI: 0.7, 4.1) relative to those totally satisfied.

Among females with overuse conditions, only education level was found to be a significant predictor of disability (p=0.044), with high school graduates at elevated risk (RH=3.6, 95% CI: 1.1, 11.9) relative to college graduates. For other musculoskeletal conditions, significant predictors included diagnosis (p<0.001) and work stress (p=0.003). Specifically, those with a diagnosis of fracture malunion or nonunion were at elevated risk (RH=5.2, 95% CI: 2.2, 11.9) relative to those diagnosed with ganglion/cyst. It appears that work stress is protective, with those seldom experiencing work stress to be 0.2 times as likely to become disabled (95% CI: 0.1, 0.5) as those who never do.

DISCUSSION

Results of this study provide a broad picture of musculoskeletal conditions and a wide range of covariates that may affect the progression towards disability. Overall, these common musculoskeletal conditions represent a substantial risk of disability discharge with a rate of 9.5 per 100 initial hospitalizations and a 5 year cumulative risk of 13.2% (95% confidence interval: 12.5%, 13.9%). Back conditions were associated with the highest 5 year cumulative risk of disability discharge. This is consistent with high back-related disability rates in civilian studies (Cheadle et al., 1994) and exposures to heavy physical demands (Liira et al., 1996) associated with many military occupations. Survival curves for specific diagnoses suggest that intervertebral disc degeneration and displacement are the most severe conditions, as indicated by their steep slopes within the initial 12 months of follow-up.

Multivariate survival analysis techniques identified the adjusted risk of disability discharge for covariates subsequent to an initial musculoskeletal hospitalization. Predictors varied considerably between genders as well as diagnostic groups. For males, significant predictors included older age group, lower pay grade, intermediate length of service, lower job satisfaction, greater work stress, recurrent musculoskeletal hospitalizations, diagnosis, occupational category, heavy physical demands, and heavy cigarette smoking. Fewer predictors were identified for females, including lower education level, shorter length of service, lower job satisfaction, lower work stress, and diagnosis. As suggested by the IOM (1995) and Feuerstein et al. (1997), perhaps women in the military are affected by unique physical and psychosocial factors beyond the 22 covariates included in this investigation. Because of the dramatically number fewer of women in the study population (N=2246) relative to men (N=13,013), there may have been significantly less power to identify predictors of disability among women. This may explain why only five covariates were found to be significant for women while ten covariates were identified for men. However, another study also found far fewer significant predictors among women than among men (Pinsky et al., 1987), suggesting that these findings are consistent and valid.

Findings: Of particular interest is the finding of very large relative hazards for males 35+ years old for overuse (RH=21.4, 95% CI: 2.7, 169.5) and other musculoskeletal (RH=29.3, 95% CI: 3.7, 229.9) conditions. This is consistent with several other studies of musculoskeletal-related disability (Berkowitz and Feuerstein, in press; MacKenzie et al., 1997; Liira et al., 1996; Badley and Ibanez, 1994; Cheadle et al., 1994; Hubert et al., 1993; Volinn et al., 1991; Leigh, 1985). The NIOSH review of musculoskeletal disorders and workplace factors suggests that "loss of tissue strength with age may increase the probability or severity of soft tissue damage from a given insult" (Bernard, 1997). The effect of older age has a slightly different interpretation in this paper than in the studies cited above; the outcome for those studies is the incidence of musculoskeletal-related injury or disability, whereas the outcome of the dissertation is the development of disability following the incidence of a condition.

Based on the findings of greater disability risk with increasing age, we might also expect an increasing risk with length of service, which is highly correlated with age. However, we found males with 1-4 years of service to have the highest risk of disability for back, overuse, and other conditions, while males with 7-12 months of service had the highest risk for knee conditions. Among females, those with the shortest length of service (≤ 6 months) were at highest risk for knee conditions while those with 1-4 years of service were at greatest risk for back conditions. This presents the unusual scenario whereby increased risk is associated with an increase in age but a decrease in both pay grade and length of service. While older persons may not heal as readily as younger persons, those in higher pay grades may not have as stringent physical demands associated with their jobs. Similarly, they may not need to return to as high a level of physical capacity as those in lower pay grades and with less time in service. Younger Army personnel, who tend to perform more physically demanding jobs, have also been found to have a higher risk of repeat injury (Schneider et al., 1998), possibly associated with higher levels of physical capacity required to perform their jobs. Surprisingly, heavy physical demands were not associated with elevated risk of disability, as others have identified (Cheadle et al., 1994; Makela et al., 1993). Perhaps the broad categorization scheme for physical demands resulted in some misclassification bias, thereby diluting the effect of this factor.

Among males with overuse conditions, frequent work stress was associated with increased risk of disability (RH=2.8, 95% CI: 1.2, 6.2). This finding is consistent with the magnitude of risk found by Berkowitz and Feuerstein (in press) for higher work stress in relation to low back disability in Army soldiers (OR=2.7). Also, those not satisfied with their job were at elevated risk (RH=1.7) among both males and females with knee conditions. These findings support the hypothesis that work stress and job satisfaction may play a fundamental role in the development of musculoskeletal conditions (Bongers et al., 1993) and their resulting physical disability (Williams et al., 1998). However, inconsistencies in the magnitude and direction of effect associated with work stress across diagnoses and gender suggests the need to better understand this complex relationship.

Recurrent hospitalization, a surrogate measure of injury severity in some cases and of healing in others, was associated with increased risk for males with knee conditions (RH=1.4, 95% CI: 1.1, 1.7) or other conditions (RH=1.4, 95% CI: 1.0, 2.1), but not back or overuse conditions. One may have expected recurrent hospitalization to have a greater relative hazard for knee and overuse conditions and to be highly significant among back conditions as well. However, the requirement that the principal diagnosis in later hospitalizations exactly match the fourth or fifth digit ICD code may have resulted in a lack of sensitivity for this measure. Other research has suggested that the level of agreement for external cause of injury (E) coding is greater at the level of the third digit than at the fourth or fifth (Langlois et al., 1995). It is likely that an increased level of agreement would have been obtained by using the third digit level of the nature of injury (N) coding as well.

Although a lower level of education was found to be an independent predictor of disability discharge among women for knee (RH=8.8) and overuse (RH=3.6) conditions, it was not found to be predictive among males for any diagnostic group. Similarly, other studies have found education to be the lone predictor among women, other than age, of good function (Pinsky et al., 1987). Many studies have identified education level as one of the strongest predictors of disability resulting from musculoskeletal conditions such as low back pain, lower extremity fracture, and rheumatoid arthritis (Deyo and Tsui-Wu, 1987; Deyo and Diehl, 1988; MacKenzie et al., 1997; Badley and Ibanez, 1994; Makela et al., 1993; Hubert et al., 1993; Pinsky et al., 1987; Pincus and Callahan, 1985). Pincus and Callahan proposed education level to be "... a composite or surrogate variable, reflecting intrinsic abilities, income, access to and use of medical facilities, levels of personal responsibilities for health care, problem-solving experience, ..." and others. Perhaps the military environment, unique in its command-oriented structure, minimizes the effect of formal education on the development of physical disability. Also, the fact that even those with the least education had attained a high school diploma limits the variation in education level and may have muted its effect.

Smoking is a significant predictor of disability among males for knee injuries (RH=1.7), but not back injuries. There is a significant literature that relates smoking to the incidence of back conditions (Deyo and Bass, 1989; Tsai et al., 1992; Svensson et al., 1983; Finkelstein, 1995; O'Connor and Marlowe, 1993; Owen and Damron, 1984; Reynolds et al., 1994; Battié et al., 1989; Boshuizen et al., 1993; Frymoyer et al., 1980; Kelsey et al., 1984; Biering-Sørensen & Thomsen, 1986; Heliövarra et al., 1991; Saraste and Hultman, 1987). A recent review suggests that cigarette smoking may be associated with the progression of musculoskeletal conditions to disability (Lincoln et al., in progress). However, there is relatively little to suggest that knee conditions (as a specific lower extremity injury) would be affected by cigarette smoking (White, 1995; Reynolds et al., 1994; Jones et al., 1993).

The finding that chondromalacia has the highest risk for disability among knee conditions may also be considered surprising. Perhaps the physical demands of military life combined with limited treatment options combine to increase the risk of disability discharge relative to meniscal and ligamentous injuries.

Limitations: There are several concerns with using HRA data in these analyses. Although many variations of the HRA have been shown to be valid, reliable, and internally consistent (Eddington and Yen, 1994), this specific instrument has not been tested for these parameters. Another concern regards the stability and accuracy of behavioral practices in Army personnel and whether the measures, as recorded by the HRA prior to their hospitalization, are likely to be the same at the time of initial musculoskeletal hospitalization. An effort to assess whether smoking patterns tend to change among this population was performed and excellent agreement was found in smoking practices between the first and second HRA (kappa=0.74, 95% CI (0.71, 0.77)). Also, the opportunity for simultaneous equation bias exists, whereby the dependent variable (disability) and covariate (smoking) may have a two-way causal relationship (i.e., smoking may increase the risk of disability, or disability may encourage one to smoke) (Leigh, 1985). In an effort to minimize this, the last personnel file update (which occur every six months) immediately prior to the initial hospitalization was used to provide information as accurate as possible. This is an important point as the subject may have changed their job after their hospitalization. Similarly, if the HRA was taken on multiple occasions, the survey occurring closest to the hospitalization was used in data collection.

Another potential limitation is the validity of self-reported behavior associated with responding to the HRA. A previous meta-analysis has indicated that self-reported tobacco use is accurate in most studies (Patrick et al., 1994). In addition, the study cohort appears to be slightly older and has a higher pay grade/rank than both Army personnel who experienced a musculoskeletal-related hospitalization and active duty personnel in general as well. This may stem from a length of service bias resulting from the requirement that the cohort subjects must take the Health Risk Appraisal. Because age was associated with the development of disability (at least among men), this additional 2 to 3 years of age on average among the study cohort should be recognized.

A potential limitation involves the hospitalization, since it does not necessarily capture the initial injury or event. In studies by Tomlinson et al. (1987) and Reynolds et al. (1994), only 3 and 2.4 percent, respectively, of musculoskeletal injuries/conditions that were reported to sick call resulted in hospitalization. Therefore, following subjects from initial hospitalization only provides a partial view of the natural history and most likely underestimates the length of the condition's history.

This study is intended to be generalizable to an adult population with activity levels that approach those of active duty Army personnel. However, attempts to generalize the findings to civilians should be made with caution. Despite some differences in civilian and military work environments, this study population represented a wide variety of occupational groups, most of which had directly comparable tasks to those found in civilian jobs.

Strengths: The primary strength of this study is the ability to collect a wide array of exposure data and follow subjects over time to determine the likelihood of disability discharge. The key to the success of this study is the linkage of several high quality data sources to assess demographic, behavioral, psychosocial, occupational, and clinical factors. Such a linkage of relevant data systems is one of the identified research needs identified by the NIOSH National Occupational Research Agenda Traumatic Injury Team as necessary for effective research (1998).

The study includes a range of potential confounders in a study of disability development, and provides significant insight into the natural history of many prevalent health conditions. In addition, the tremendous size of the target population offers the ability to follow a cohort with power to detect associations between covariates and the outcome of interest. The study benefits from a reduction of the antagonistic employee-employer relationship that is often evident with civilian worker compensation cases. Also, the determination of disability is fairly objective relative to the experience of private sector disability policy. Lastly, the use of a cohort study design rather than a case-control or cross-sectional design provides more credible evidence of a causal association between the independent factors and outcome of interest.

CONCLUSION

Musculoskeletal conditions requiring hospitalization represent a substantial risk of disability resulting in discharge from the U.S. Army. Back conditions are shown to be the most severe and have the highest 5 year cumulative risk of disability. Demographic, behavioral, psychosocial, occupational, and clinical characteristics are associated with disability discharge, supporting the multivariate nature of disability. Modifiable risk factors such as job satisfaction, work stress, and smoking suggest possible targets for intervention to achieve a successful rehabilitation.

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Table 1. Data Sources and Variables

Data File	Variable	Derived Indices
Personnel	Age Sex Race/Ethnicity Pay grade Military occupational specialty (duty) Education level Marital status Number of dependents Length of time in service	
Hospitalization	Principal diagnosis Disposition (discharge) date Recurrent hospitalizations and dates Total sick days Disposition (discharge outcome) Alcohol-related comorbidity	
Health Risk Appraisal	Exercise* Diet* Sleep* Alcohol use Tobacco use Height# Weight# Job satisfaction Work stress Reason for taking HRA	*Health practices index #Body mass index
Disability	Final status Date of Medical Board	
Loss	Reason for separation Separation from service date	
Army Regulation 611-201	Physical demand (MOS-based)	

Table 2. Functional Groups and Diagnostic Categories of ICD-9-CM Codes for Musculoskeletal Disorders and Sprain/Strains (N=15,268)

Functional Group	Diagnostic Category (no. of subjects)	ICD-9-CM Code
1. Back conditions	A. Non-specific back pain (691)	724.2 Lumbago 724.5 Backache, unspecified
	B. Displacement of intervertebral disc (1608)	722.0 Displacement of cervical intervertebral disc without myelopathy 722.1 Displacement of thoracic or lumbar intervertebral disc without myelopathy (includes .1, .10, .11) 722.2 Displacement of intervertebral disc, site unspecified, without myelopathy
	C. Degeneration and other disc disorders (130)	722.4 Degeneration of cervical intervertebral disc 722.5 Degeneration of thoracic or lumbar intervertebral disc (includes .51, .52) 722.6 Degeneration of intervertebral disc, site unspecified 722.7 Intervertebral disc disorder with myelopathy (includes .70, .71, .72, .73) 722.8 Postlaminectomy syndrome (includes .80, .81, .83) 722.9 Other and unspecified disc disorder (includes .90, .91, .92, .93)
2. Knee conditions	D. Meniscal injury (3691)	717.0 Old bucket handle tear of medial meniscus 717.1 Derangement of anterior horn of medial meniscus 717.2 Derangement of posterior horn of medial meniscus 717.3 Other and unspecified derangement of medial meniscus 717.4 Derangement of lateral meniscus (includes .4, .40, .41, .42, .43, .49) 717.5 Derangement of meniscus, not elsewhere classified 836.0 Tear of medial cartilage or meniscus of knee, current 836.1 Tear of lateral cartilage or meniscus of knee, current 836.2 Other tear of cartilage or meniscus of knee, current
	E. Cruciate ligament injury (2266)	717.83 Old disruption of anterior cruciate ligament 717.84 Old disruption of posterior cruciate ligament 844.2 Sprain/strain of cruciate ligament of knee
	F. Collateral ligament injury (564)	717.81 Old disruption of lateral collateral ligament 717.82 Old disruption of medial collateral ligament 844.0 Sprain/strain of lateral collateral ligament 844.1 Sprain/strain of medial collateral ligament
	G. Chondromalacia (923)	717.7 Chondromalacia of patella
3. Overuse conditions	H. Synovitis and tenosynovitis (817)	727.0 Synovitis and tenosynovitis (includes .0, .00, .01, .02, .03, .04, .05, .06, .09)

Functional Group	Diagnostic Category (no. of subjects)	ICD-9-CM Code
	I. Carpal and cubital tunnel syndromes (547)	354.0 Carpal tunnel syndrome 354.2 Lesion of ulnar nerve (Cubital tunnel syndrome)
	J. Rotator cuff injury (330)	726.1 Rotator cuff syndrome of shoulder and allied disorders (includes .1, .10, .11, .12, .19) 840.3 Infraspinatus (muscle) (tendon) 840.4 Rotator cuff (capsule) 840.5 Subscapularis (muscle) 840.6 Supraspinatus (muscle) (tendon)
4. Other MS Conditions	K. Ganglion and cyst of synovium, tendon, and bursa (1356)	727.4 Ganglion and cyst of synovium, tendon, and bursa (includes .4, .40, .41, .42, .43, .49)
	L. Bunion and deformities of toe (1533)	727.1 Bunion 735.0 Hallux valgus (acquired)
	M. Malunion and nonunion of fracture (812)	733.8 Malunion and nonunion of fracture (includes .8, .81, .82)

Table 3. Comparisons of Study Cohort with All Musculoskeletal Hospitalizations and Sample of Active Duty Personnel

Sociodemographic Characteristic	Study Cohort (N=15,268)		MS Hosp.1989-95 (N=52,021)		Chi-square: MS Hosp. vs. Study Cohort	Active Duty Sample (N=44,045)		Chi-square: Active Duty vs. Study Cohort
	N	%	N	%		N	%	
Sex								
Male	13,013	85.2	44,505	85.6	0.7	38,342	87.1	34.2
Female	2246	14.7	7516	14.4	(p=0.40)	5654	12.8	(p<0.0001)
Age								
<21	547	3.6	6515	12.6	1094.6	7645	17.4	2543.8
21-25	3955	26.0	13,980	26.9	(p<0.0001)	13,241	30.1	(p<0.0001)
26-34	5751	37.7	17,182	33.1		14,424	32.7	
35+	4987	32.7	14,223	27.4		8645	19.6	
Pay grade/rank								
E1-E3	1706	11.2	10,934	21.3	873.0	9732	22.1	1562.0
E4-E6	8702	57.0	27,709	53.9	(p<0.0001)	22,853	51.9	(p<0.0001)
E7-E9	2095	13.7	6186	12.0		4693	10.7	
W1-W5	446	2.9	1120	2.2		1061	2.4	
O1-O3	1266	8.3	3091	6.0		1513	3.4	
O4-O10	974	6.4	2395	4.6		4178	9.5	
Race/ethnicity								
White	9603	62.9		N/A		27,134	61.6	62.0
Black	4375	28.7				12,267	27.9	(p<0.0001)
Hispanic	603	3.9				2211	5.0	
American Indian/Alaskan Native	87	0.6				264	0.6	
Asian/Pacific Islander	219	1.4				916	2.1	
Other	371	2.4				1207	2.8	
Education level								
No H.S. diploma	47	0.3		N/A		199	0.5	175.9
HS grad/GED	11,258	73.7				33,222	75.5	(p<0.0001)
Some college	1017	6.7				2388	5.4	
College degree	2721	17.8				6907	15.7	
Unknown	220	1.4				1311	3.0	

N/A: Race/ethnicity and Education level are either coded differently or not available in the hospitalization file, so comparisons between the group with musculoskeletal hospitalizations and study cohort cannot be made.

Table 4. Demographics and Bivariate Analysis of Study Population

Category	Strata	Disability Discharge (N=1454), (%)		Study Cohort (N=15,268), (%)		Disability Rate (per 100 admits)	Log-rank (equality) *	Log-rank (trend)**
Sex	Male	1236	85.0	13,013	85.2	9.50	p=.78	-
	Female	218	15.0	2246	14.7	9.71		
	Missing	0	0	9	0.1	0.00		
Age Groups	<21	31	2.1	1057	6.9	2.93	p=.00	p=.00
	21-25	435	29.9	3582	23.5	12.14		
	26-34	691	47.5	5550	36.4	12.45		
	35 +	297	20.4	5079	33.3	5.85		
Race/Ethnicity	White	957	65.8	9603	62.9	9.97	p=.02	-
	Black	398	27.4	4375	28.7	9.10		
	Hispanic	50	3.4	603	3.9	8.29		
	American Indian/ Alaskan Native	10	0.7	87	0.6	11.49		
	Asian/Pacific Islander	13	0.9	219	1.4	5.94		
	Other	26	1.8	371	2.4	7.01		
	Unknown	-	-	10	0.1	0.00		
Education Level	No H.S. diploma	4	0.3	47	0.3	8.51	p=.00	p=.00
	H.S. grad/GED	1274	87.6	11,258	73.7	11.32		
	Some college	62	4.3	1017	6.7	6.10		
	College degree	101	6.9	2721	17.8	3.71		
	Unknown	13	0.9	220	1.4	5.91		
	Missing	0	0	5	0.0	0.00		
Pay Grade	E1-E3	289	19.9	1706	11.2	16.94	p=.00	p=.00
	E4-E6	1010	69.5	8702	57.0	11.61		
	E7-E9	72	5.0	2095	13.7	3.44		
	W1-W5	12	0.8	446	2.9	2.69		
	O1-O3	56	3.9	1266	8.3	4.42		
	O4-O10	15	1.0	974	6.4	1.54		
	Cadets	0	0	77	0.5	0.00		
	Missing	0	0	2	0.0	0.00		
Total		1454		15,268		9.52	-	

* test of equality of survival distributions for different levels of a factor

** test for linear trend across levels of factor

Table 5. Occupational Characteristics and Bivariate Analysis of Study Population

Category	Strata	Disability Discharge (N=1454), (%)		Study Cohort (N=15,268), (%)		Disability Rate (per 100 admits)	Log-rank (equality) *	Log-rank (trend)**
Enlisted Occupational Specialty	Direct combat	14	1.0	238	1.6	5.88	p=.00	-
	Electronic equip repair	480	33.0	3599	23.6	13.34		
	Commun & intelligence	17	1.2	274	1.8	6.20		
	Health care	97	6.7	865	5.7	11.21		
	Other technical	28	1.9	206	1.3	13.59		
	Support & administration	56	3.9	636	4.2	8.81		
	Electrical/mech repair	186	12.8	1600	10.5	11.63		
	Craftsman	145	10.0	1840	12.1	7.88		
	Service & supply	55	3.8	485	3.2	11.34		
	Non-occupational	290	19.9	2752	18.0	10.54		
	Warrant Officers	12	0.8	444	2.9	2.70		
	Officers	71	5.0	2238	14.6	3.17		
Physical Demand (Enlisted only)	Not determined	80	5.5	1131	7.4	7.07	p=.00	p=.00
	Light	23	1.6	233	1.5	9.87		
	Medium	60	4.1	802	5.3	7.48		
	Moderately heavy	196	13.5	1736	11.4	11.29		
	Heavy	12	0.8	138	0.9	8.70		
	Very heavy	791	54.4	6172	40.4	12.82		
	Missing	209	14.4	2372	15.5	8.81		
Work Stress	Often	173	11.9	1263	8.3	13.70	p=.00	p=.00
	Sometimes	384	26.4	3637	23.8	10.56		
	Seldom	478	32.9	5820	38.1	8.21		
	Never	389	26.8	4089	26.8	9.51		
Job Satisfaction	Not satisfied	233	16.0	1762	11.5	13.22	p=.00	p=.00
	Somewhat	327	22.5	3012	19.7	10.86		
	Mostly	382	26.3	4687	30.7	8.15		
	Totally	188	12.9	2793	18.3	6.73		
	N/A	288	19.8	2553	16.7	11.28		
Total		1454		15,268		9.52	-	

* test of equality of survival distributions for different levels of a factor

** test for linear trend across levels of factor

Table 6. Cox Proportional Hazards Models by Diagnostic Group (Men)

Covariate	Back (N=1160)		Knee (N=3155)		Overuse (N=742)		Other (N=2627)	
	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval
Age Group								
<21years	1.00	-	1.00	-	1.00	-	1.00	-
21-25 years	11.10	1.53 80.54	2.71	1.56 4.68	8.64	1.16 64.45	15.98	2.20 116.30
26-34 years	13.09	1.81 94.68	3.95	2.24 6.95	8.43	1.12 63.57	24.41	3.31 180.21
35+ years	9.19	1.25 67.87	3.66	1.88 7.11	21.43	2.71 169.53	29.34	3.74 229.87
Pay Grade								
E1-E3	1.44	0.69 3.03	6.27	2.78 14.11	*not*	*significant*	2.16	0.44 10.60
E4-E6	1.88	1.09 3.22	3.48	1.64 7.36			1.23	0.27 5.65
E7-E9	1.00	-	1.00	-			0.79	0.16 4.01
W1-W5							Unstable	-
O1-O3							0.36	0.06 2.31
O4-O10							1.00	-
Length of Service								
≤6 months	1.04	0.23 4.68	1.95	0.86 4.45	5.02	0.57 44.36	Unstable	-
7-12 months	0.79	0.10 5.92	3.63	1.85 7.11	Unstable	-	1.75	0.51 5.99
1-4 years	2.79	1.81 4.29	2.32	1.51 3.55	10.08	4.40 23.09	3.67	1.87 7.23
5-10 years	1.74	1.20 2.51	1.77	1.21 2.61	5.75	2.68 12.33	3.08	1.66 5.70
>10 years	1.00	-	1.00	-	1.00	-	1.00	-
Job Satisfaction								
Not satisfied	*not*	*significant*	1.71	1.15 2.56	*not*	*significant*	*not*	*significant*
Somewhat satisfied			1.59	1.10 2.29				
Mostly satisfied			1.26	0.88 1.79				
Totally satisfied			1.00	-				
Work Stress								
Often	*not*	*significant*	1.02	0.70 1.49	2.76	1.22 6.24	*not*	*significant*
Sometimes			0.96	0.72 1.28	1.15	0.58 2.30		
Seldom			0.69	0.52 0.91	1.19	0.64 2.20		
Never			1.00	-	1.00	-		
Recurrent Hospitalizations								
No	*not*	*significant*	1.00	-	*not*	*significant*	1.00	-
Yes			1.36	1.08 1.72			1.42	0.98 2.06

<u>Occupational Category</u>												
Direct combat	*not*	*significant*		*not*	*significant*		*not*	*significant*		0.64	0.06	7.49
Electrical equipment repair										1.52	0.31	7.42
Communication & intell										Unstable	-	
Health care										0.51	0.09	2.91
Other technical										1.22	0.19	7.87
Support & administration										0.99	0.18	5.56
Electrical/mechanical repair										0.75	0.15	3.86
Craftsman										0.75	0.14	3.86
Service & supply										0.85	0.14	5.19
Non-occupational										0.79	0.16	4.01
Warrant Officers & Officers										1.00	-	
<u>Diagnostic Category</u>												
Ganglion/cyst							*not*	*significant*		1.00	-	
Bunion/toe deformities										1.10	0.71	1.71
Malunion/nonunion										2.53	1.71	3.73
Meniscal injury				1.00	-							
Cruciate ligament injury				1.13	0.88	1.44						
Collateral ligament injury				1.23	0.82	1.83						
Chondromalacia				1.52	1.11	2.08						
Non-specific back pain	1.00	-										
Disc displacement	1.52	1.13	2.06									
Disc degeneration	1.94	1.05	3.58									
<u>Smoking</u>												
Nonsmoker	*not*	*significant*		1.00	-		*not*	*significant*		*not*	*significant*	
Former smoker				0.85	0.60	1.23						
Light (<1 pack/day)				1.29	0.98	1.69						
Heavy (1+ pack/day)				1.67	1.26	2.22						
<u>Physical Demands</u>												
Light	1.00	-		1.00	-		1.00	-		*not*	*significant*	
Medium	0.23	0.07	0.72	0.86	0.33	2.23	0.56	0.11	2.83			
Moderately heavy	1.01	0.46	2.23	0.87	0.37	2.04	0.24	0.06	0.99			
Heavy	0.95	0.24	3.70	3.50	0.86	14.21	2.43	0 .37	15.84			
Very Heavy	0.93	0.44	1.99	1.25	0.55	2.81	0.69	0.21	2.28			

Not significant - not included in final model; Unstable - too few subjects in strata

Table 7. Cox Proportional Hazards Models by Diagnostic Group (Women)

Covariate	Back (N=252)		Knee (N=210)		Overuse (N=334)		Other (N=952)	
	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval
Education								
High school grad/GED	*not*	*significant*	8.76	2.67 28.70	3.62	1.10 11.92	*not*	*significant*
Some college			1.73	0.18 16.82	1.21	0.20 7.24		
College degree			1.00	-	1.00	-		
Length of Service								
≤6 months	1.41	0.30 6.63	6.26	1.87 20.92	*not*	*significant*	*not*	*significant*
7-12 months	Unstable	-	2.62	0.51 13.57				
1-4 years	2.65	1.33 5.31	2.43	0.94 6.33				
5-10 years	1.37	0.63 2.99	1.54	0.55 4.30				
>10 years	1.00	-	1.00	-				
Job Satisfaction								
Not satisfied	*not*	*significant*	1.73	0.73 4.13	*not*	*significant*	*not*	*significant*
Somewhat satisfied			0.56	0.24 1.33				
Mostly satisfied			0.73	0.33 1.61				
Totally satisfied			1.00	-				
Work Stress								
Often	*not*	*significant*	*not*	*significant*	*not*	*significant*	0.68	0.27 1.69
Sometimes							0.87	0.47 1.62
Seldom							0.25	0.12 0.54
Never							1.00	-
Diagnostic Category								
Non-specific back pain	1.00	-	*not*	*significant*	*not*	*significant*		
Disc displacement	2.37	1.28 4.37						
Disc degeneration	0.91	0.12 7.13						
Ganglion/cyst							1.00	-
Bunion/toe deformities							1.10	0.60 2.03
Malunion/nonunion							5.15	2.22 11.91

Not significant - not included in final model; Unstable - too few subjects in strata

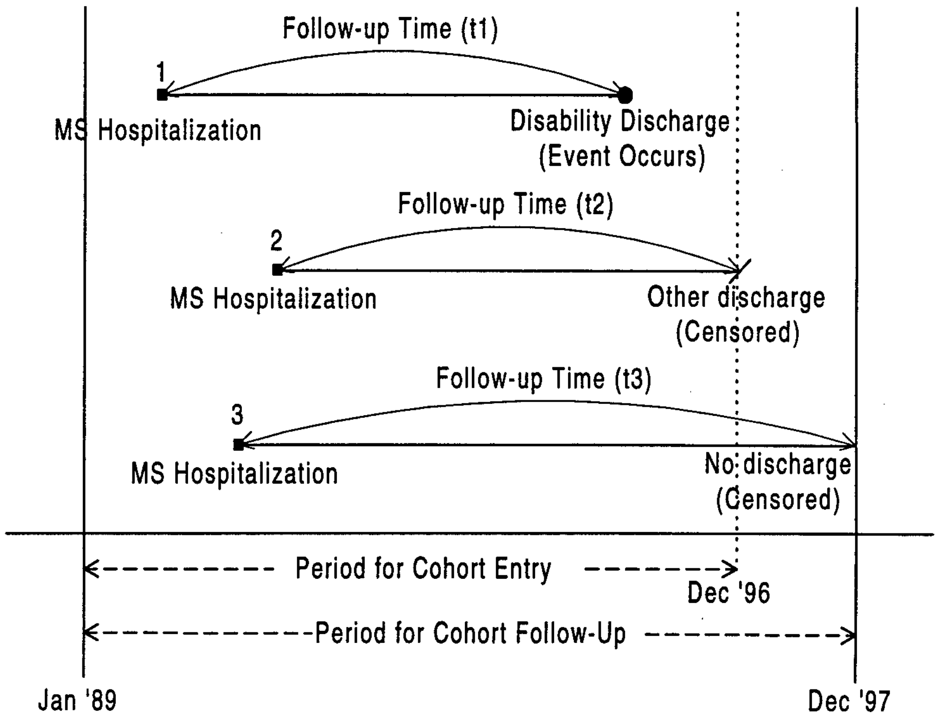


Figure I. Outcome Classification and Follow-up Period

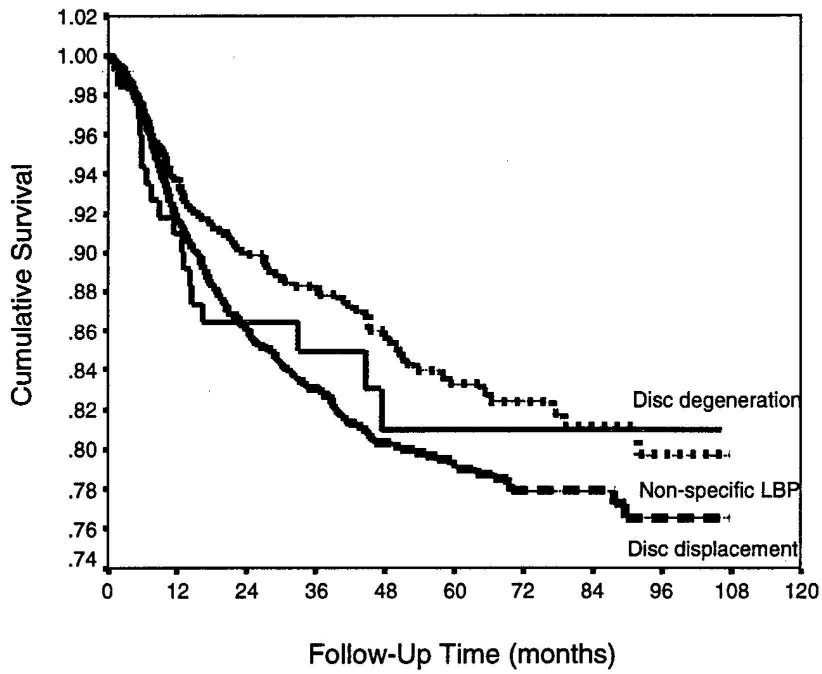


Figure 2. Time to Disability Discharge Among Back Conditions, U.S. Army, 1989-1997

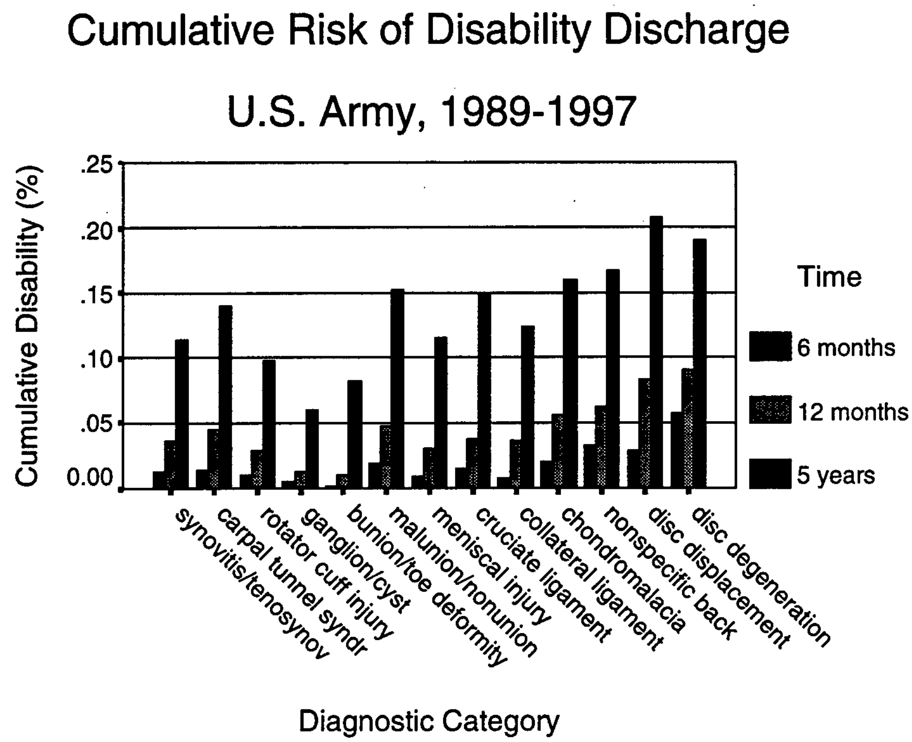


Figure 3. Cumulative Risk of Disability Discharge, U.S. Army, 1989-1997

Figure 4. Time to Disability Discharge

Among Knee Conditions

U.S. Army, 1989-1997

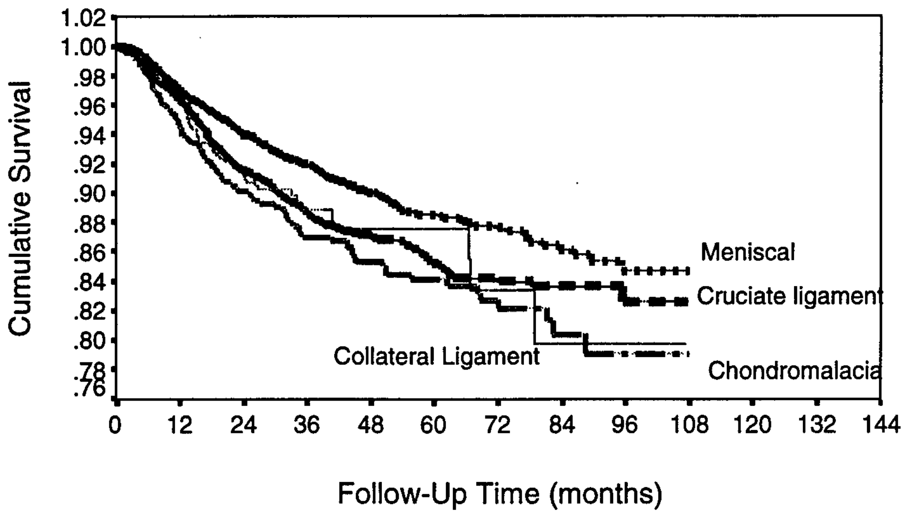


Figure 5. Time to Disability Discharge

Among Overuse Conditions

U.S. Army, 1989-1997

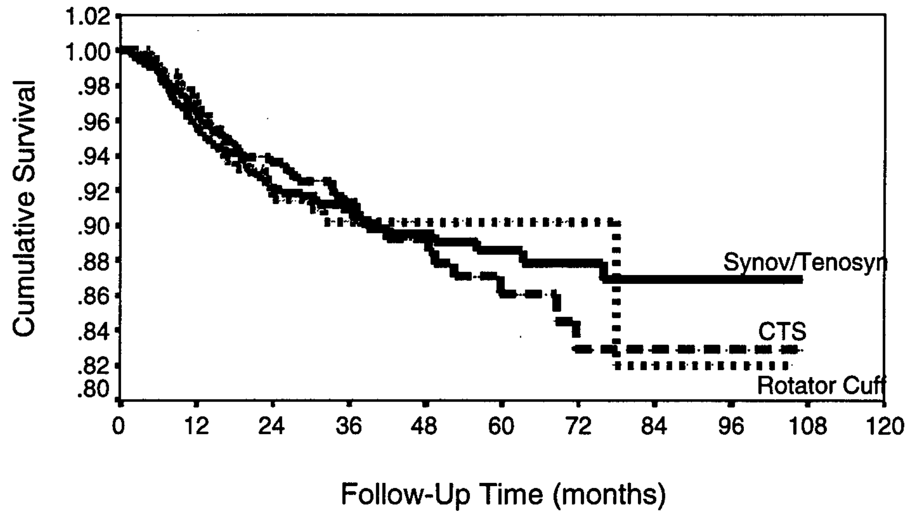
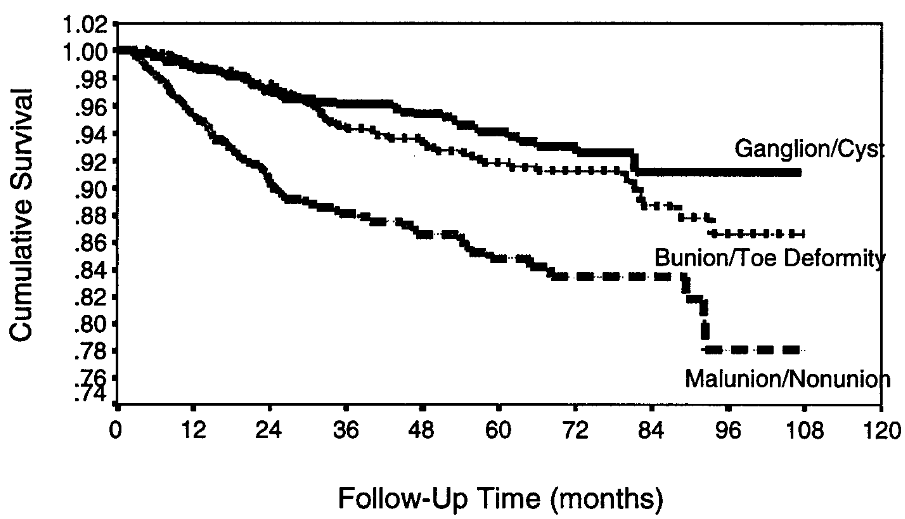


Figure 6. Time to Disability Discharge Among

Other Musculoskeletal Conditions

U.S. Army, 1989-1997



Chapter 4

The Effect of Cigarette Smoking on Musculoskeletal-Related Disability

Andrew E. Lincoln, MS [1]
Gordon S. Smith, MB, ChB, MPH [1]
Paul J. Amoroso, MD, MPH [2]
Nicole S. Bell, ScD [3]

[1] Center for Injury Research and Policy, Department of Health Policy and Management, Johns Hopkins School of Public Health, Baltimore, MD

[2] U.S. Army Research Institute of Environmental Medicine, Natick, MA

[3] Social Sectors Development Strategies, Inc., Natick, MA

Address for correspondence and reprint requests:
Andrew E. Lincoln, M.S.
The Johns Hopkins Center for Injury Research and Policy
624 N. Broadway
Baltimore, MD 21205
(410)614-4023, fax (410)614-2797
alincoln@jhsph.edu

5 Tables, 3 Figures

Key words: musculoskeletal disorders, disability, cigarette smoking, military

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ABSTRACT

Purpose: To describe the effect of cigarette smoking on the development of physical disability among persons hospitalized with a musculoskeletal disorder; to determine whether smoking affects disability from different diagnoses to varying degrees; and to suggest mechanisms of smoking's effects based on the findings.

Design: A retrospective cohort design involving 5 linked databases was utilized to follow U.S. Army personnel from their initial musculoskeletal-related hospitalization, which occurred between the years 1989 and 1996, through to the subsequent development of physical disability as indicated by a disability-related discharge, up to 1997. We assessed the effect of different levels of smoking while controlling for demographic, psychosocial, occupational, and clinical characteristics. Subjects included 15,140 U.S. Army personnel hospitalized for one of 13 common musculoskeletal disorders.

Results: Results of this study indicate an association between smoking level and disability discharge for all musculoskeletal categories combined. Kaplan-Meier estimates illustrated distinct survival curves among different smoking levels and log-rank tests for trend demonstrated associations between smoking level and cumulative risk for disability discharge for all knee disorders (e.g., meniscal injury ($p<0.001$), cruciate ligament injury ($p=0.08$), collateral ligament injury ($p=0.003$), and chondromalacia ($p=0.03$)), rotator cuff injury ($p=0.01$), and intervertebral disc displacement ($p=0.05$). However, when adjusting for stronger predictors in multivariate Cox proportional hazards models, smoking was significantly associated

with only meniscal injuries (light smokers (<1 pack/day) had a 44% greater risk than nonsmokers and heavy smokers (1+ pack/day) had a 49% greater risk) and all diagnostic categories combined (heavy smokers had a 21% greater risk). Former smokers appear to be protected, though not significantly (RH=0.94, 95% CI: 0.80, 1.11). Among current smokers with meniscal injuries, 38% of disability discharges were attributable to smoking, while the attributable risk of disability due to smoking among current smokers and nonsmokers was 18%.

Conclusion: Results provide evidence of an association between heavy smoking and the development of disability following hospitalization for musculoskeletal disorders in the U.S. Army. A potential biologic mechanism to explain smoking's effect on meniscal injuries may involve smoking's effect of reducing blood flow to the already limited vascularization of the meniscus. The finding suggests that medical management of patients with various musculoskeletal disorders, and in particular meniscal injuries, should address cigarette smoking to reduce the risk of subsequently developing a physical disability.

INTRODUCTION

Since the initial surgeon general's report in 1964 (PHS, 1964), smoking has been recognized as one of the most important public health issues of our time and the most important preventable cause of death and disease in the United States (McGinnis and Foege, 1993; DHHS, 1989). Just as smoking is one of the greatest risk factors for poor health, musculoskeletal disorders represent a health outcome that has garnered much public attention, particularly within occupational health interests, and become either the focus or a strong component of substantial clinical and governmental efforts. Among these are the development of clinical treatment guidelines (Harris, 1997; Bigos et al., 1994), a proposed federal occupational health standard (ANPR 57 FR 34192), and inclusion as a major issue on the National Occupational Research Agenda (NIOSH, 1996).

Musculoskeletal disorders represent a tremendous cost to society; they comprise the largest proportion of work-related injuries and illnesses (BLS, 1997) and 315 million office visits costing approximately $150 billion in 1992 (Yelin and Callahan, 1995). Musculoskeletal disorders also result in various levels of disability, ranging from limitations in activities of daily living (Williams et al., 1998; Deyo and Diehl, 1988) to an inability to return to work (Hazard et al., 1996; MacKenzie et al., 1997; Lancourt and Kettelhut, 1992; Volinn et al., 1991; MacKenzie et al., 1987), with significant ramifications for family members and coworkers alike. However, few investigators have examined the role of smoking in the development of work-related disability (Berkowitz and Feuerstein, in press; Rothenbacher et al., 1998;

Hubert and Fries, 1994; Makela et al., 1993; Leigh, 1985). Recognizing work-related disability to be a multifactoral development (Katz et al., 1997; Bongers et al., 1993; Cats-Baril and Frymoyer, 1991; Feuerstein and Thebarge, 1991), it is neither appropriate nor possible to identify a single "smoking gun" as the source of such a complex process as the development of disability. However, the detailed investigation of possible contributing factors is essential to identify which factors are most strongly associated with disability and which of those are modifiable and amenable to intervention.

U.S. Army personnel engage in a variety of active and physically demanding tasks, many with the potential for injury. As a result, musculoskeletal disorders are associated with the majority (51%) of diagnoses resulting in disability discharge from service (Feuerstein et al., 1997) and are a critical concern in terms of readiness and cost. Despite the tremendous cost of musculoskeletal-related disability payments to veterans (lifetime costs of $485 million to newly disabled Army personnel in 1993 (Jones and Hanson, 1996) and average costs of $277,000 per permanent disability case (Department of Defense Actuary, submitted), few studies have examined the health outcome of discharge from the service due to disability (Feuerstein et al., 1997; Berkowitz and Feuerstein, in press). Recently, the role of smoking has received greater attention in relation to the incidence of injuries among Army personnel (Amoroso et al., 1996a; Amoroso et al., 1996b; Amoroso et al., 1996c; Reynolds et al., 1996; Reynolds et al., 1994; Dettori et al., 1996; Jones et al., 1993), though none has addressed smoking in relation to disability. Therefore, we attempted to address the role of smoking as an independent risk factor in the development of disability in a large cohort with the following objectives: to describe the effect of cigarette smoking on the development of physical disability among persons hospitalized with a musculoskeletal disorder; to determine whether smoking affects disability associated with different diagnoses to varying degrees; and to suggest mechanisms of smoking's effects based on these findings.

A recent prospective study identified smoking to be an independent risk factor for early retirement due to physical disability (Rothenbacher et al., 1998). However, this study did not address potential biological mechanisms associated with different types of disorders, such as those related to the musculoskeletal system which comprised 40% of the study population. A systematic review of the literature identified smoking to be a significant risk factor for several commonly occurring musculoskeletal disorders (Lincoln et al., in progress). Reasonable evidence was presented to illustrate that tobacco and its constituents may affect wound healing as well as potentially increase the risk of an injury occurring. A multifactoral model portraying the injury-to-disability transition was offered to clinicians and researchers to assist their consideration of preventable risk factors that endanger a successful recovery following injury. This paper seeks to verify that model using a population-based sampling frame.

METHODS

Study Design

A retrospective cohort design was used to follow U.S. Army personnel from their initial musculoskeletal-related hospitalization, which occurred between the years 1989 and 1996, through the development of physical disability, up to 1997. We assessed the role of smoking while controlling for the effects of 11 other covariates, many of which are considered to be potential confounders of associations between exposures and health outcomes.

Cohort Definition

To be included in the study, cohort subjects must have met several criteria: 1) been on active duty at the time of hospitalization; 2) been hospitalized for a specified musculoskeletal disorder or severe sprain/strain during the period 1989 to 1996 (Table 1); and 3) completed a health risk appraisal (HRA) at some point during the same time period. There were 16,348 persons who met those initial criteria. Because the goal of the study was to capture subjects at their first hospital admission for one of the diagnoses of interest, those hospitalized for the same condition prior to 1989 (N=1053) or having a disability rating preceding the initial musculoskeletal hospitalization (N=27) were disqualified and eliminated from the cohort. In addition, cigarette smoking data was not available for 148 subjects, who were then excluded, leaving the total number of qualifying subjects to be 15,120.

Data Sources

Data were obtained from the Total Army Injury and Health Outcomes Database (TAIHOD), a collection of available databases in the Army that was recently compiled primarily for injury prevention and women's health research (Amoroso et al., 1997). Unique identifiers (scrambled social security numbers) enabled us to link information across databases, in effect permitting us to track the natural history of a subject's condition. The completeness of the Army's administrative databases provided excellent follow-up with minimal loss of cohort subjects and the standardized disability evaluation process provided an objective outcome measure.

This study made use of four types of data: demographics, health practices, health outcomes (hospitalizations), and functional outcomes (disability ratings). Five separate databases were linked: personnel, hospitalization, health risk appraisal (HRA), disability, and loss from service. The personnel file provided information on demographic variables. The hospitalization file offered information on date of admission, diagnosis, and recurrent hospitalization. The health risk appraisal data allowed us to incorporate behavioral influences beyond the personal characteristics and occupational exposures that are commonly utilized in epidemiological studies. The disability file offered data on outcomes from disability evaluations. The loss from service file provided valuable information regarding censoring of subjects.

Smoking Status

Smoking status was categorized as nonsmoker, former smoker, and current smoker based on self-reported HRA survey data. Current smokers were further classified as either a light smoker (<1 pack/day) or a heavy smoker (1+ pack/day) as defined in a recent worldwide survey of smoking in the U.S. military (Kroutil et al. 1994). Although smoking status may be considered a time-dependent variable, the status reported at the first survey was used to represent smoking as a fixed variable. This was done because only a small proportion of subjects had taken the HRA on more than one occasion. Furthermore, efforts to assess the stability of smoking patterns yielded excellent agreement when comparing smoking practices before and after the initial hospitalization (kappa=0.74, 95% CI: 0.71, 0.77, N=1482). This high level of agreement offers confidence to the validity of the smoking status measure despite its construction as a fixed, rather than time-dependent, variable.

Potential Confounding Factors

A number of potentially confounding factors associated with the primary risk factor (smoking) and primary outcome (disability discharge) were examined. These were: age, sex, race/ethnicity, education, pay grade/rank, job class, physical demand level of job, work stress, job satisfaction, length of service, and diagnostic category.

Age, sex, race/ethnicity, education, pay grade/rank, job class, and length of service were all derived from the personnel file, which is considered to be the most complete and reliable of the administrative data sources. Physical demands for specific occupational titles were classified as Light, Medium, Moderately Heavy, Heavy, and Very Heavy according to Army regulations detailing occupational specialties (Department of the Army, 1994). These categories represent maximum upper body strength requirements as required for "combat conditions" performance for enlisted personnel and are considered to be a good indicator of physical demands of the job. The Department of Defense occupational coding structure was used to classify enlisted personnel into one of 10 occupational categories based on the subject's duty occupational specialty (DoD Directive No. 1312.1-M, 1989). Work stress and job satisfaction measures were obtained from the HRA using four point scales (often, sometimes, seldom or never under too much stress; not, somewhat, mostly, or totally satisfied).

Diagnostic Categories

Forty diagnoses were selected from the principal diagnosis field in the hospitalization database. Diagnoses included both "acute" injuries within ICD-9-CM codes 836, 840, or 844 and "chronic" conditions (710-739, 354) that represent similar clinical presentations. These 40 diagnoses were classified into 13 functional groupings for analysis. Discussions with an injury researcher with experience in coding (Gordon Smith, MD, MPH, Johns Hopkins School of Hygiene and Public Health), a practicing orthopedist (Richard Hinton, MD, MPH, MPT, MEd, Johns Hopkins School of Medicine), and a practicing physiatrist (Tamara Lauder, MD, Johns Hopkins School of Medicine) were performed to develop the diagnostic categories and functional groupings that involve similar mechanisms of injury or healing. We decided not to examine all musculoskeletal injuries; rather we sought to focus on a group of clean diagnostic and clinical entities since the whole group of musculoskeletal conditions cover a broad range of widely discrepant disorders.

Outcomes

The outcome considered in this analysis was time (number of months) to disability discharge. Disability discharge was defined as having been assigned the following status at a medical evaluation board at some point between the initial hospitalization and the end of 1997: 1) permanent disability/retirement (disability rating of at least 20% or having at least 20 years of service); 2) severance without benefits (disability rating of less than 20% and having less than 20 years of services); or 3) temporary disability. Because this study was designed to document the incidence of disability following musculoskeletal hospitalization, all medical discharges for disability were included, regardless of the primary cause or condition. Time to disability was determined from the point of the initial musculoskeletal hospitalization until the subject was either medically discharged, discharged (censored) for some other reason (e.g., honorable discharge, leaves of own accord, death), or censored because of the end of the follow-up period. Although an individual may have been evaluated for disability determination on more than one occasion (i.e., if they were placed on temporary disability), their first occurrence in the disability database was used to represent the outcome from the Physical

Evaluation Board. Persons were assigned a temporary disability for a condition that had not yet stabilized. Frequently, they went on to receive a permanent disability status. But even among those who were later found fit for duty, they had been off work for significant lengths of time and, therefore, were included in the study as "disability" cases.

Time-to-Event Analysis

Kaplan-Meier estimates of survival time for each diagnostic category were used to assess the five year cumulative risk of disability discharge among smoking levels. A log-rank test for trend was performed to evaluated the association between disability discharge and the four levels of smoking exposure (nonsmoker, former smoker, light smoker, and heavy smoker).

The Cox proportional hazards model was used to estimate the combined effect of multiple risk factors and the contribution of each factor independently (Collett, 1994). Nonsmokers were selected as the reference group, so a relative hazard and 95% confidence interval that exceeded unity indicated a significantly increased risk of disability relative to nonsmokers at the $\alpha=0.05$ level, while controlling for other potential confounders. Similarly, a relative hazard and 95% confidence interval less than unity indicated a significantly decreased risk of disability relative to nonsmokers. All covariates were modeled using a forced entry approach to assess the adjusted effect of smoking levels on disability. Separate models were generated for each of the 13 diagnostic categories to determine the effect of smoking and the variation in smoking's influence across diagnoses. All covariates were analyzed in categorical form and all analyses were performed with SPSS for Windows, Release 7.5.2 (Chicago, IL).

Attributable risks were calculated using crude incidence rates of disability discharge following hospitalization among current smokers and nonsmokers. Among subjects with meniscal injuries, the attributable risks due to smoking among current smokers and in the total study cohort were calculated according to the techniques described by Kahn and Sempos (1989).

RESULTS

Distribution of Covariates Among Smoking Levels

Of the 15,120 study subjects, 7799 (51.6%) were nonsmokers, 2610 (17.3%) were former smokers, 2766 (18.3%) were light smokers, and 1945 (12.9%) were heavy smokers. The distribution of covariates among the four levels of smoking is presented in Tables 2 and 3. Pearson chi-square tests identified significant differences ($p<0.001$) in the distribution of smoking levels across each covariate. Although some of the covariates may be collinear (e.g., age and length of service, education and pay grade/rank), they were included to illustrate the range of characteristics associated with different levels of smoking.

Heavy smokers were overrepresented among males, whites, older persons (35+ years of age), those with more than 10 years of service, those with lower levels of education (high school graduates), middle (E4-E6) and higher (E7-E9) ranking enlisted persons, and enlisted personnel in job classifications of direct combat, electronic equipment repair, communication and intelligence, support and administration, and electrical and mechanical repair. The corresponding physical demand level of many of these occupational specialties were reflected in the overrepresentation of "very heavy" physically demanding jobs among heavy smokers. Interestingly, heavy smokers were also overrepresented among those who "often" experience work stress and those "not satisfied" with their jobs. Persons with certain diagnostic categories, such as carpal and cubital tunnel syndromes, malunion and nonunion of fracture, nonspecific back pain, and intervertebral disc displacement were also overrepresented among heavy smokers.

At the other end of the spectrum, nonsmokers were overrepresented by females, younger persons (<35 years of age), persons of black, Hispanic, and Asian/Pacific Islander race/ethnicity, officers, those with 10 or fewer years of service, those with college degrees, and those with diagnoses of synovitis and tenosynovitis, cruciate ligament injury, or collateral ligament injury. Regarding psychosocial aspects of work, both persons who "never" experience work stress and those "totally satisfied" with their job were overrepresented among nonsmokers.

Distribution of Outcome Among Smoking Levels

A comparison of five year cumulative risk of disability discharge across smoking levels for each diagnostic category is presented in Table 4. For all musculoskeletal diagnoses combined, heavy smokers had the highest risk of disability discharge (17.6%), followed by light smokers (15.8%), nonsmokers (12.2%), and then former smokers (10.3%). Assuming that the association between smoking level and outcome may be considered linear in the order of nonsmokers, former smokers, light smokers, and heavy smokers, a log-rank test for trend indicated a highly significant result ($p<0.001$). This suggested the slope of a line to represent this association was other than zero, and appeared to be correlated with increasing level of smoking. The effect of different levels of smoking was further demonstrated by their distinct survival curves illustrated in Figure 1. Using all musculoskeletal diagnoses combined, heavy smokers demonstrated the greatest risk, followed by light smokers, nonsmokers, and former smokers (log-rank test for equality: $p<0.001$).

Several diagnostic categories, though far from all, demonstrated this same trend of increasing risk of disability with increasing level of smoking (Table 4). The trend is strongest for meniscal injury ($p<0.001$), and was also significant for collateral ligament injury ($p=0.003$), rotator cuff injury ($p=0.011$), chondromalacia ($p=0.031$), intervertebral disc displacement ($p=0.050$), and cruciate ligament injury ($p=0.080$), albeit marginally. Meniscal injuries in particular demonstrated a dramatic difference in risk between current smokers (including both light and heavy) and nonsmokers, as illustrated in Figure 2.

In all but two categories (ganglion/cyst and nonspecific back pain), former smokers demonstrated a lower risk of disability than did nonsmokers, suggesting that former smokers are more resistant to developing a disability. This "J-shape" effect is seen for the five year cumulative risk for all diagnostic categories in Figure 3.

Role of Smoking on Disability Discharge

The relative hazards (RH) and 95% confidence intervals (CI) of disability discharge across smoking levels for each diagnostic group produced by multivariate Cox proportional hazards models are presented in Table 5. In addition to smoking, the models included the covariates age group, sex, race/ethnicity, education, pay grade/rank, length of service, and work stress. The covariates of physical demand and job satisfaction were not included because of a large number of missing values (40.5% and 19.7%, respectively). Also, occupational specialty was excluded from the models because of its collinearity with pay grade/rank.

For all diagnostic groups considered together, former smokers had a slightly decreased risk of disability discharge (RH=0.94, 95% CI: 0.80, 1.11) relative to nonsmokers, while light smokers had an elevated risk (RH=1.11, 95% CI: 0.97, 1.27) and heavy smokers had a significantly higher risk (RH=1.21, 95% CI: 1.04, 1.42). Among specific diagnostic categories, only meniscal injuries demonstrated a significantly higher risk for smoking, with light smokers having 1.44 times the risk of nonsmokers (95% CI: 1.07, 1.94) and heavy smokers having 1.49 times the risk of nonsmokers (95% CI: 1.06, 2.11). Former smokers with meniscal injuries were also at elevated risk (RH=1.06), though this was not statistically significant. When cases with meniscal injuries were removed from the group of all diagnostic categories, the trend of former smokers having a decreased risk (RH=0.92), light smokers having a slightly elevated risk (RH=1.04), and heavy smokers having the greatest risk (RH=1.16) persisted, though none of these results were statistically significant. Evidence of an association between smoking and disability was also evident for the diagnoses of carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, and chondromalacia, though not at the $\alpha=0.05$ significance level.

Among current smokers with meniscal injuries, 37.9% of disability discharges were attributable to smoking, or more than one of every three disability discharges. For the entire cohort (excluding former smokers), the attributable risk of disability due to smoking was 18.2% (95% CI: 9.1%, 27.3%), so nearly every fifth subject with a meniscal injury resulting in a disability discharge was related to smoking. These findings are very comparable to those of Rothenbacher et al. (1998).

DISCUSSION

Results of this study indicate an association between smoking level and disability discharge for all musculoskeletal diagnoses combined. Kaplan-Meier estimates illustrated distinct survival curves among different smoking levels and log-rank tests for trend demonstrated linear associations between smoking level and cumulative risk for disability discharge for all knee disorders (e.g., meniscal injury, cruciate ligament injury, collateral ligament injury, and chondromalacia), rotator cuff injury, and intervertebral disc displacement, but not for synovitis/tenosynovitis, carpal/cubital tunnel syndrome, ganglion/cyst, bunion/toe deformities, malunion/nonunion of fracture, nonspecific back pain, or intervertebral disc degeneration. However, when adjusting for stronger predictors in multivariate Cox proportional hazards models (e.g., age, diagnosis, pay grade), smoking was significantly associated with only meniscal injuries (light smokers had a 44% greater risk than nonsmokers and heavy smokers had a 49% greater risk) and all diagnostic categories combined (heavy smokers had a 21% greater risk). Results from Cox models for carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, and chondromalacia suggest that smoking may affect disability following these diagnoses, though not at statistically significant levels.

To our knowledge, this represents the first identified association between smoking and development of disability among persons with meniscal injuries. Since this finding persists after adjusting for various psychosocial and occupational factors, it suggests the presence of a physiological mechanism. This may involve the poor vascularization of the menisci, whereby the vascular structure only penetrates the peripheral 10 - 25% and at least the inner 75% of the menisci is avascular (Arnoczky and Warren, 1982). Arnoczky and Warren suggest that "... isolated lesions in the avascular area would lack the blood supply necessary for an inflammatory and reparative response." Given that the menisci are provided with a limited blood supply in even the healthiest person, the effects of smoking (e.g., vasoconstriction, hypoxia, and immune suppression (Amoroso et al., 1996a)), may further decrease the supply of nutrients to the damaged tissue and result in the interruption of the healing process and long-term dysfunction. Similar arguments have been espoused to explain the associations of smoking with wound healing, bone metabolism, low back pain (particularly related to a herniated disc), postoperative infection, and, in general, the healing of injured tissue with limited vascularization (Kwiatkowski et al., 1996). The most likely mechanism is nicotine's effect to constrict the microcirculation and reduce blood supply to the target organ, either indirectly through hormone release or directly through the production of catecholamines, which promote peripheral vasoconstriction (Kwiatkowski et al., 1996). Meniscal injuries represent perhaps the cleanest diagnostic group of injuries in this cohort and are more likely to undergo a standardized treatment regimen (including surgery) than other groups, such as back conditions. The relative uniformity associated with this condition and the fact that it was the most numerous (N=3653) may have contributed to its demonstrated association with smoking. Because of the substantial attributable risk associated with smoking (38% among current smokers), the introduction of smoking cessation efforts at the time of diagnosis may be an effective intervention to prevent the development of physical disability and save the associated costs.

It is somewhat surprising that the multivariate analyses did not identify a significant association between smoking and disability from any of the back disorders or carpal tunnel syndrome, given the substantial literature associating smoking with the *incidence*, though not necessarily the development of disability, of these conditions (Deyo and Bass, 1989; Tsai et al., 1992; Svensson et al., 1983; Finkelstein, 1995; O'Connor and Marlowe, 1993; Owen and Damron, 1984; Reynolds et al., 1994; Battié et al., 1989; Boshuizen et al., 1993; Frymoyer et al., 1980; Kelsey et al., 1984;

Biering-Sørensen & Thomsen, 1986; Heliövarra et al., 1991; Saraste and Hultman, 1987; Tanaka et al., 1997; Nathan et al., 1996; Vessey et al., 1990). Perhaps the fact that this was a young cohort (mean age of 31 years) with a tendency to be involved in very physically demanding jobs (68% of enlisted subjects in the "very heavy" category) and maintain high levels of physical fitness contributed to greater relative stress on the knee than on the back or other body part. In the Army, the ramifications of a bad knee may be more severe than an injury to another body part, such as the back, in terms of being able to perform your job task requirements and support your unit. Alternatively, smoking may contribute to mechanisms that lead to back pain and back injury, but do not impair the healing mechanisms that would influence subsequent disability.

Fundamental to its mission, the Army cannot afford to support individuals who cannot physically perform at a high level. Therefore, the outcome of disability used in this study may be more (or overly) sensitive relative to the "return to work" measure used with many civilian investigations of disability.

A very interesting finding was the distribution of disability discharge across smoking levels. The "J-shaped" curve representing the outcome across the range of smoking exposures suggests that former smokers are least likely to develop a disability resulting in discharge, even less so than nonsmokers. Although this trend was evident for many of the diagnoses, former smokers were never determined to be significantly at lower risk. Nonetheless, the cumulative survival curves (Figure 1) indicated that former smokers may be protected, perhaps because former smokers represent healthy survivors who have a heartier constitution than others or, more likely, they have given up smoking as part of a series of behavioral changes that contribute to improved health and decreased likelihood of developing a disability. In either event, the difference in risk of disability discharge between heavy smokers and former smokers suggests that the effects of tobacco use prior to injury are not permanent and may, in fact, be reversible. These findings have considerable importance in developing recommendations to stop smoking.

Among studies that investigate the effect of smoking in association with physical disability, the results of this study are largely consistent. In Leigh's prospective cohort study (1985), he found that cigarette smoking "...was strongly and positively associated with the probability of becoming disabled" after incurring an "accident or disease". In what is most likely the closest study in terms of methodology and outcome (i.e., development of disability), Rothenbacher et al. (1998) produced similar measures of effect for both light smokers (RH=1.3) and heavy smokers (RH=1.6) when examining a cohort of construction workers for early retirement due to physical disability. Therefore, the relatively modest risks associated with smoking appear to be confirmed, as is the slight dose-response relationship, despite the overlapping confidence intervals of relative hazards at different levels of smoking. Also, Hubert and Fries (1994) found greater number of pack-years of cigarette smoking to be predictive of physical disability in their six year follow-up of an elder university cohort (mean age: 61 years). Other studies of physical disability among elderly populations have also identified smoking as a risk factor in population-based cohort studies (Guralnik and Kaplan, 1989; Pinsky et al., 1987; Pinsky et a l., 1985), although the outcomes used in those studies are more reflective of activities of daily living than ability to work. Also, German studies from the 1970s as referenced in Rothenbacher et al. (1998) identified smokers to be at increased risk for early retirement due to disability. Virtually all of these studies demonstrating a positive association between smoking and disability have utilized cohort designs and survival analysis techniques to provide results that are generally more robust than results from case-control or cross-sectional designs.

Among studies that did not identify a positive association, Makela et al. (1993) found that "smoking was not significantly associated with any measure of disability" in their cross-sectional study of determinants of disability in Finns with musculoskeletal disorders. Smoking dropped out of Berkowitz and Feuerstein's final model of predictors of long term disability from occupational low back pain in a case-control study of U.S. Army personnel (in press). This result does not conflict with our findings, which did not demonstrate a significant association between smoking and disability among back conditions (Table 5).

Heavy smoking was found to be associated with lower levels of socioeconomic status, including lower levels of education, lower pay grade/rank, and more physically demanding jobs, as well as higher levels of stress, such as those associated with work and less job satisfaction. It is psychosocial components such as these that Amoroso et al. (1996a) suggested may represent a possible mechanism to explain why smokers have a greater risk of the occurrence of injury than nonsmokers.

In addition to the presence of a physiological mechanism, a psychosocial mechanism may exist that in effect puts smokers at greater risk of injury as a result of greater risk-taking behavior or exposure to a more hazardous environment. Applied to a disability model rather than an injury model, psychosocial factors such as being not married or divorced (Cheadle et al., 1994; Badley and Ibanez, 1994; Lehmann et al., 1993; Volinn et al., 1991), having less education (Dionne et al., 1995; Deyo and Tsui-Wu, 1987; Deyo and Diehl, 1988; MacKenzie et al., 1997; Badley and Ibanez, 1994; Makela et al., 1993; Hubert et al., 1993), having a negative perception of the workplace (Williams et al., 1998; Berkowitz and Feuerstein, in press; Bigos et al., 1992; Lancourt and Kettelhut, 1992), and having fewer coping mechanisms (Lancourt and Kettelhut, 1992; Habeck et al., 1991) may result in a person having less motivation or fewer personal resources that enable him or her to experience a successful recovery. It is most likely that a combination of such psychosocial factors and physiological effects contribute to the greater risk of disability experienced by smokers in this study.

Limitations: There are several concerns with these analyses, many of which involve the use of health risk appraisal data. Although many variations of the HRA have been shown to be valid, reliable, and internally consistent (Eddington and Yen, 1994), the version used by the Army has not been evaluated in its entirety for its validity and reliability as a predictive tool. Instead, "studies have concentrated on devising valid algorithms for risk estimates for specific topic areas within the HRA (e.g., coronary artery disease) and testing the predictive validity of those algorithms" (USACHPPM, 1994). Another concern regards the stability and accuracy of behavioral practices in Army personnel and whether the measures, as recorded by the HRA prior to their hospitalization, are likely to be the same at the time of initial musculoskeletal hospitalization. An effort to assess whether smoking patterns tend to change among this population was presented elsewhere (Lincoln et al., in progress) and excellent agreement was found in smoking practices before and after hospitalization (kappa=0.74, 95% CI: 0.71, 0.77).

Generally, the rate of missing data in military data was very low. However, there were two variables with substantial proportions of missing values: physical demands (40.5%) and job satisfaction (19.7%). Physical demands were available for all enlisted personnel except 8.7%, but were not available for officers or warrant officers. The only other variable missing more than 3.0% of values was job satisfaction, which may be considered a sensitive question for an employer to ask its employees. Perhaps subjects were concerned about the ramifications of their response in terms of future assignments and therefore did not answer the question. Efforts to impute missing data during statistical analyses were not successful. Therefore, those cases with missing data were excluded from each statistical model.

Because the behavioral data may have been obtained either before or after the initial hospitalization, there is the opportunity for simultaneous equation bias (Leigh, 1985), whereby the dependent variable (disability) and covariate (smoking) may have a two-way causal relationship (i.e., smoking may cause disability or disability may lead to smoking). In an effort to minimize this, the last personnel file update (which occur every six months) immediately prior to the initial hospitalization was used to provide information as accurate as possible. This is an important point as the subject may have changed their job after their hospitalization. Similarly, if the HRA was taken on multiple occasions, the survey occurring closest to the hospitalization was used in data collection.

This study is intended to be generalizable to both Army personnel who experienced a musculoskeletal-related hospitalization and active duty personnel in general. As presented in another paper (Lincoln et al., in progress), differences appear to be negligible in terms of sex, race/ethnicity, and education. However, the study cohort appears to be slightly older (31.0 years) than both comparison groups (29.5 years for personnel with musculoskeletal-related hospitalizations and 28.2 years for active duty sample) and has a higher pay grade/rank as well. This may stem from a length of service bias resulting from the requirement that the cohort subjects must take the Health Risk Appraisal. Since survey selection is not a random process, those with a greater length of service are more likely to have an opportunity to complete it. As expected, those with a greater length of service tend to be older and have a higher pay grade/rank. Because age was associated with the development of disability (at least among men), this additional 2 to 3 years of age on average among the study cohort should be recognized.

The prevalence of smoking in this cohort is similar to that of a worldwide survey of U.S. military personnel (Kroutil et al., 1994) in terms of age, sex, race/ethnicity, and pay grade. Overall, our cohort was 3.8% less likely to report current cigarette smoking (31.2% versus 35.0%), a difference that was fairly uniform across demographic strata. Possible explanations for this small difference include different measurement tools, different chronological times at which the surveys were administered, reticence on the part of our cohort to honestly answer the smoking questions, the inclusion of all branches of the service in the worldwide survey, and actual differences in the populations. However, the many similarities in the trends across demographic strata suggest that the data in our study were highly valid. Furthermore, the presence of a misclassification bias between subjects who developed a disability and those who did not is highly unlikely.

Strengths: The primary strength of this study is the ability to make use of a wide array of pre-injury exposure data and follow subjects over time to determine the likelihood of disability discharge. The key to the success of this study is the linkage of several high quality data sources to assess demographic, behavioral, psychosocial, occupational, and clinical factors. Such a linkage of relevant data systems is one of the identified research needs identified by the NIOSH National Occupational Research Agenda Traumatic Injury Team as necessary for effective research (1998).

The study includes a range of potential confounders in a study of disability development, and provides significant insight into one of the potential risk factors. In addition, the tremendous size of the target population offers the ability to follow a cohort with power to detect associations between levels of exposure and the outcome of interest. The determination of disability in this study benefits from a reduction of the antagonistic employee-employer relationship that is often evident with civilian worker compensation cases. Also, the determination of disability is fairly objective and standardized relative to the experience of private sector disability policy. Lastly, the use of a cohort study design rather than a case-control or cross-sectional design provides more credible evidence of a causal association between smoking and disability.

CONCLUSION

Heavy smoking represents a substantial risk of disability resulting in discharge from the U.S. Army for meniscal injuries. However, this association was not evident for all musculoskeletal disorders. A potential mechanism of smoking's effect may involve decreased blood supply and interruption of the healing process. The findings suggest that medical management of patients with various musculoskeletal disorders, and in particular meniscal injuries, should address cigarette smoking to reduce the risk of developing a physical disability.

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Table 1. Diagnostic Categories of ICD-9-CM Codes for Musculoskeletal Disorders and Sprain/Strains (N=15,120)

Diagnostic Category	Number of Subjects	ICD-9-CM Code
A. Synovitis and tenosynovitis	810	727.0 Synovitis and tenosynovitis (includes .0, .00, .01, .02, .03, .04, .05, .06, .09)
B. Carpal and cubital tunnel syndromes	542	354.0 Carpal tunnel syndrome 354.2 Lesion of ulnar nerve (Cubital tunnel syndrome)
C. Rotator cuff injury	325	726.1 Rotator cuff syndrome of shoulder and allied disorders (includes .1, .10, .11, .12, .19) 840.3 Infraspinatus (muscle) (tendon) 840.4 Rotator cuff (capsule) 840.5 Subscapularis (muscle) 840.6 Supraspinatus (muscle) (tendon)
D. Ganglion and cyst of synovium, tendon, and bursa	1344	727.4 Ganglion and cyst of synovium, tendon, and bursa (includes .4, .40, .41, .42, .43, .49)
E. Bunion and deformities of toe	1517	727.1 Bunion 735.0 Hallux valgus (acquired)
F. Malunion and nonunion of fracture	807	733.8 Malunion and nonunion of fracture (includes .8, .81, .82)
G. Meniscal injury	3653	717.0 Old bucket handle tear of medial meniscus 717.1 Derangement of anterior horn of medial meniscus 717.2 Derangement of posterior horn of medial meniscus 717.3 Other and unspecified derangement of medial meniscus 717.4 Derangement of lateral meniscus (includes .4, .40, .41, .42, .43, .49) 717.5 Derangement of meniscus, not elsewhere classified 836.0 Tear of medial cartilage or meniscus of knee, current 836.1 Tear of lateral cartilage or meniscus of knee, current 836.2 Other tear of cartilage or meniscus of knee, current
H. Cruciate ligament injury	2247	717.83 Old disruption of anterior cruciate ligament 717.84 Old disruption of posterior cruciate ligament 844.2 Sprain/strain of cruciate ligament of knee
I. Collateral ligament injury	560	717.81 Old disruption of lateral collateral ligament 717.82 Old disruption of medial collateral ligament 844.0 Sprain/strain of lateral collateral ligament 844.1 Sprain/strain of medial collateral ligament
J. Chondromalacia	915	717.7 Chondromalacia of patella
K. Non-specific back pain	683	724.2 Lumbago 724.5 Backache, unspecified

Diagnostic Category	Number of Subjects	ICD-9-CM Code
L. Displacement of intervertebral disc	1588	722.0 Displacement of cervical intervertebral disc without myelopathy 722.1 Displacement of thoracic or lumbar intervertebral disc without myelopathy (includes .1, .10, .11) 722.2 Displacement of intervertebral disc, site unspecified, without myelopathy
M. Degeneration and other disc disorders	129	722.4 Degeneration of cervical intervertebral disc 722.5 Degeneration of thoracic or lumbar intervertebral disc (includes .51, .52) 722.6 Degeneration of intervertebral disc, site unspecified 722.7 Intervertebral disc disorder with myelopathy (includes .70, .71, .72, .73) 722.8 Postlaminectomy syndrome (includes .80, .81, .83) 722.9 Other and unspecified disc disorder (includes .90, .91, .92, .93)

Table 2. Demographic Characteristics of the Study Population

Characteristic & Strata	Nonsmoker		Former Smoker		Light Smoker		Heavy Smoker		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
<u>Sample size</u>	7799	51.6	2610	17.3	2766	18.3	1945	12.9	15,120	100
<u>Average follow-up</u> (months)	39.3	(SD=27.1)	39.9	(SD=27.1)	35.9	(SD=26.1)	36.6	(SD=26.4)	38.4	(SD=26.9)
<u>Sex</u> ($p<.001$)										
Male	6527	50.7	2251	17.5	2309	17.9	1785	13.9	12,872	100
Female	1266	56.5	358	16.0	455	20.3	160	7.1	2239	100
<u>Age</u> (mean years) ($p<.001$)	30.1	(SD=7.3)	33.5	(SD=7.9)	30.0	(SD=6.9)	32	(SD=7.0)	30.9	(SD=7.4)
<21	596	57.0	111	10.6	249	23.8	90	8.6	1046	100
21-25	2070	58.0	421	11.8	705	19.8	370	10.4	3566	100
26-34	2965	53.7	838	15.2	1035	18.8	680	12.3	5518	100
35 +	2168	43.4	1240	24.8	777	15.6	805	16.1	4990	100
<u>Race/Ethnicity</u> ($p<.001$)										
White	4483	47.1	1751	18.4	1605	16.9	1679	17.6	9518	100
Black	2618	60.5	597	13.8	930	21.5	184	4.3	4329	100
Hispanic	329	55.2	137	23.0	97	16.3	33	5.5	596	100
American Indian/Alaskan	44	52.4	16	19.0	15	17.9	9	10.7	84	100
Asian/Pacific Islander	129	59.7	28	13.0	45	20.8	14	6.5	216	100
Other	192	52.3	78	21.3	72	19.6	25	6.8	367	100
<u>Education Level</u> ($p<.001$)										
No H.S. diploma	19	41.3	4	8.7	15	32.6	8	17.4	46	100
H.S. grad/GED	5302	47.5	1767	15.8	2406	21.6	1686	15.1	11,161	100
Some college	479	47.5	246	24.4	162	16.1	121	12.0	1008	100
College degree	1861	69.4	542	20.2	166	6.2	113	4.2	682	100

Table 3. Occupational Characteristics of the Study Population

Characteristic & Strata	Nonsmoker		Former Smoker		Light Smoker		Heavy Smoker		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Pay Grade (p<.001)										
E1-E3	884	52.1	194	11.4	420	24.8	198	11.7	1696	100
E4-E6	4236	49.0	1309	15.1	1876	21.7	1220	14.1	8641	100
E7-E9	801	39.0	527	25.7	322	15.7	404	19.7	2054	100
W1-W5	212	47.9	130	29.3	51	11.5	50	11.3	443	100
O1-O3	998	79.2	162	12.9	66	5.2	34	2.7	1260	100
O4-O10	599	63.3	281	29.7	28	3.0	39	4.1	947	100
Physical Demand (p<0.001)										
Light	113	49.1	39	17.0	45	19.6	33	14.3	230	100
Medium	439	55.2	122	15.3	163	20.5	72	9.0	796	100
Moderately heavy	853	49.4	301	17.4	341	19.7	233	13.5	1728	100
Heavy	72	53.3	24	17.8	20	14.8	19	14.1	135	100
Very heavy	2899	47.3	926	15.1	1325	21.6	977	15.9	6127	100
Work Stress (p<0.001)										
Often	598	47.6	183	14.6	242	19.3	233	18.6	1256	100
Sometimes	1817	50.1	644	17.8	648	17.9	516	14.2	3625	100
Seldom	2994	51.6	1056	18.2	1029	17.8	718	12.4	5797	100
Never	2190	53.8	662	16.2	787	19.3	435	10.7	4074	100
Job Satisfaction (p<0.001)										
Not satisfied	811	46.3	285	16.3	357	20.4	299	17.1	1752	100
Somewhat	1552	51.8	492	16.4	541	18.1	409	13.7	2994	100
Mostly	2404	51.5	859	18.4	830	17.8	579	12.4	4672	100
Totally	1510	54.2	518	18.6	467	16.8	290	10.4	2785	100

Table 4. Comparison of Five Year Cumulative Risk of Disability Discharge Among Different Levels of Smoking by Diagnostic Category

Diagnostic Category	Nonsmoker	Former Smoker	Light Smoker	Heavy Smoker	Log-rank test for trend
Synovitis and tenosynovitis	11.7%	6.9%	14.6%	13.8%	1.48 (p=0.224)
Carpal and cubital tunnel syndromes	13.8%	9.5%	15.2%	17.7%	1.09 (p=0.297)
Rotator cuff injury	6.9%	5.9%	13.9%	21.8%	6.55 (p=0.011)
Ganglion and cyst of synovium, tendon, and bursa	4.8%	5.6%	4.6%	13.1%	2.35 (p=0.125)
Bunion and deformities of toe	8.6%	3.1%	11.9%	6.3%	0.00 (p=0.978)
Malunion and nonunion of fracture	17.1%	16.1%	9.1%	17.4%	0.92 (p=0.338)
Meniscal injury	10.0%	7.5%	17.2%	16.4%	18.81 (p<.001)
Cruciate ligament injury	14.2%	13.0%	18.9%	17.2%	3.07 (p=0.080)
Collateral ligament injury	9.1%	7.3%	19.3%	27.6%	8.71 (p=0.003)
Chondromalacia	14.0%	13.0%	17.3%	24.1%	4.67 (p=0.031)
Non-specific back pain	17.3%	18.4%	16.4%	14.0%	1.08 (p=0.300)
Displacement of intervertebral disc	19.4%	16.8%	24.3%	26.6%	3.84 (p=0.050)
Degeneration and other disc disorders	19.1%	16.2%	31.9%	8.9%	0.94 (p=0.333)
All diagnostic categories	12.2%	10.3%	15.8%	17.6%	31.75 (p<.001)

Table 5. Cox Proportional Hazards Models for Disability Discharge by Diagnostic Group

Diagnostic Category	Nonsmoker	Former Smoker		Light Smoker		Heavy Smoker	
	Relative Hazard	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval	Relative Hazard	95% Confidence Interval
Synovitis and tenosynovitis	1.00	0.68	0.30, 1.53	1.00	0.54, 1.86	1.10	0.48, 2.48
Carpal and cubital tunnel syndromes	1.00	0.97	0.36, 2.61	1.65	0.73, 3.72	1.74	0.67, 4.55
Rotator cuff injury	1.00	0.84	0.20, 3.55	1.46	0.44, 4.88	2.99	0.95, 9.38
Ganglion and cyst of synovium, tendon, and bursa	1.00	1.11	0.51, 2.42	0.69	0.29, 1.61	1.90	0.90, 4.01
Bunion and deformities of toe	1.00	0.39	0.14, 1.11	1.46	0.87, 2.44	0.54	0.16, 1.82
Malunion and nonunion of fracture	1.00	1.12	0.59, 2.11	0.71	0.38, 1.31	0.97	0.52, 1.81
Meniscal injury	1.00	1.06	0.72, 1.54	1.44*	1.07, 1.94	1.49*	1.06, 2.11
Cruciate ligament injury	1.00	0.96	0.65, 1.44	1.10	0.79, 1.54	0.96	0.62, 1.49
Collateral ligament injury	1.00	0.78	0.29, 2.13	1.63	0.79, 3.34	1.80	0.73, 4.43
Chondromalacia	1.00	1.42	0.79, 2.56	1.04	0.60, 1.79	1.47	0.87, 2.50
Nonspecific back pain	1.00	1.14	0.65, 1.97	0.92	0.50, 1.68	0.85	0.42, 1.73
Displacement of intervertebral disc	1.00	0.75	0.51, 1.10	0.90	0.64, 1.27	1.12	0.79, 1.60
Degeneration and other disc disorders	1.00	0.82	0.16, 4.38	1.19	0.19, 7.33	0.09	0.01, 1.37
All diagnostic categories	1.00	0.94	0.80, 1.11	1.11	0.97, 1.27	1.21*	1.04, 1.42
All diagnostic categories except meniscal injuries	1.00	0.92	0.77, 1.10	1.04	0.89, 1.22	1.16	0.97, 1.38

* $p<0.05$

Note: The risk estimates have been adjusted for age group, sex, race/ethnicity, education, pay grade/rank, length of service, and work stress.

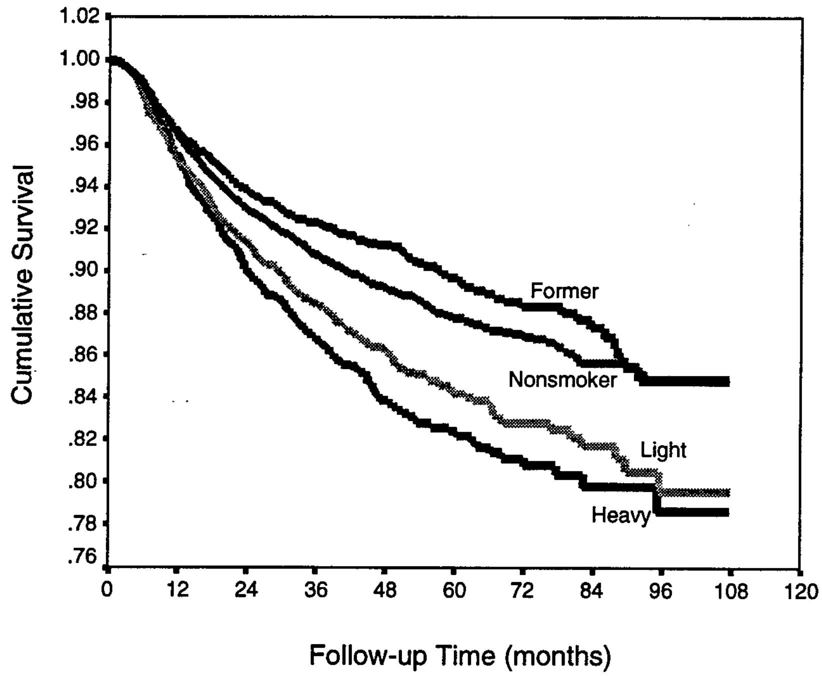

Figure 1. Time to Disability Discharge by Cigarette Smoking Level, U.S. Army, 1989-1997

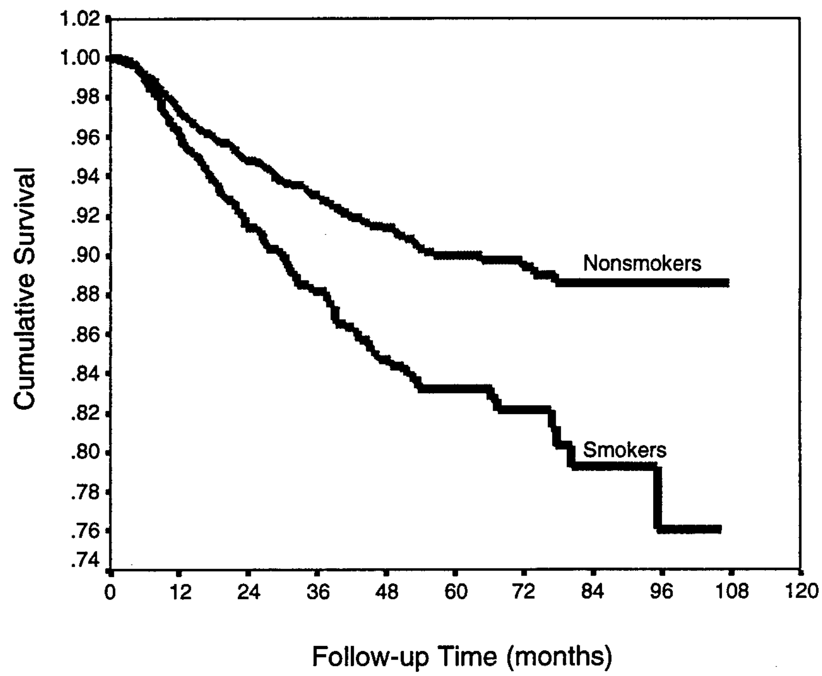

Figure 2. Time to Disability Discharge Following Meniscal Injury by Cigarette Smoking Level, U.S. Army, 1989-1997

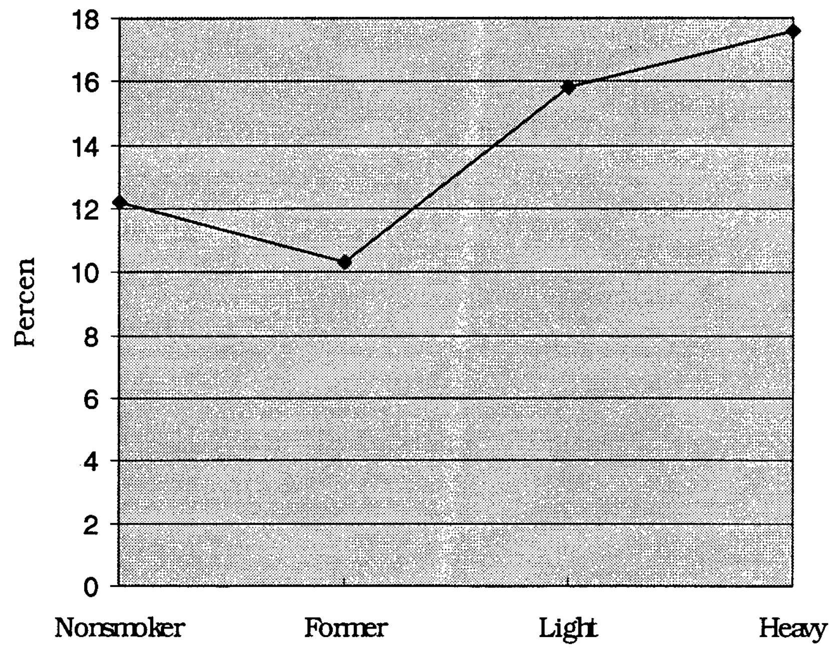

Figure 3. Five Year Cumulative Risk of Disability Across Smoking Levels for All Diagnostic Categories, U.S. Army, 1989-1997

CHAPTER 5: DISCUSSION

This research was intended to investigate risk factors for the development of physical disability following the incidence of common musculoskeletal disorders. The literature review conducted as the first part of this research clearly identified smoking as a potential risk factor for the development of disability, and was used as a basis for developing the statistical models in the manuscripts. The initial analysis assessed the occurrence of disability discharge from the Army among 15,000 subjects who were hospitalized with one of thirteen categories of musculoskeletal diagnoses and the risk factors associated with the development of disability. The second analysis investigated the role of cigarette smoking specifically as a risk factor for disability discharge within each of the musculoskeletal diagnoses. By identifying risk factors and suggesting causal relationships, this effort represented an initial step to understand the development of disability and ultimately reduce its incidence and severity. Results of these findings are to be utilized to verify elements in the model of disability development, propose theories of causality, and suggest interventions.

This chapter summarizes the results from the study and their significance (5.1) and then reviews the limitations and strengths of the study (5.2). Next, possible directions for future research (5.3) are discussed, both in terms of refinements to the present study and ideas for an intervention study. The chapter continues with policy implications on disability in the Army (5.4), in terms of opportunities for secondary prevention efforts, smoking policy, and the physician's role in smoking cessation. A conclusion (5.5) summarizes what has been achieved by this effort.

5.1 Summary and Significance of Results

This study began with a systematic review of the literature that clearly identified smoking to be a significant risk factor for several commonly occurring musculoskeletal disorders, including low-back pain (OR=1.2-3.0), lower extremity injury (1.9), carpal tunnel syndrome (1.6), and fracture/non-union (4.1-7.9). Reasonable evidence was available to illustrate that tobacco and its constituents may affect wound healing as well as potentially increase the risk of an injury incidence. A multifactoral model portraying the injury-to-disability transition was developed to assist clinicians and researchers in their consideration of preventable risk factors that endanger a successful recovery following injury.

The primary intentions of the analyses were to: 1) present the natural history of several common musculoskeletal disorders; 2) identify predictors of disability associated with functional diagnostic groupings; and 3) investigate the effect of smoking on disability for each of the diagnostic categories. The findings from each component are summarized in the following sections.

5.1.1 Natural History of Musculoskeletal Disorders

Overall, the musculoskeletal disorders included in this study represent a substantial risk of long-term disability with a rate of 9.52 disability discharges from the Army per 100 initial hospitalizations for these conditions. Risk of disability varied considerably by diagnosis, ranging from the lowest rates for ganglion/cyst (3.98/100 hospitalizations) and bunion/toe deformities (5.15/100 hospitalizations) to the highest rates for back-related diagnoses, including intervertebral disc displacement (16.67/100 hospitalizations), intervertebral disc degeneration (14.62/100 hospitalizations), and nonspecific back pain (13.75/100 hospitalizations).

Kaplan-Meier estimates indicated that intervertebral disc degeneration and displacement are the most hazardous conditions with respect to risk of disability discharge, as indicated by the steep slopes on the survival curves during the initial 15 months of follow-up. Intervertebral disc degeneration posed the greatest cumulative risk of disability at 6 months (5.7%) and 12 months (9.1%). At 5 years, the cumulative risk of disability was greatest for intervertebral disc displacement (20.8%), followed by intervertebral disc degeneration (19.1%) and nonspecific back pain (16.7%).

Knee conditions were the most common diagnosis among this study cohort, representing 49% of cases. Chondromalacia presented the greatest cumulative 5 year risk (15.9%) among knee conditions, indicating that a chronic condition may involve greater risk than a more acute knee injury, such as to the cruciate ligament (14.8%), collateral ligament (12.4%), or meniscus (11.5%).

Another diagnosis with a relatively high 5 year cumulative disability risk is malunion and nonunion of fracture (15.2%), although the nature of the diagnosis denotes a complication by its definition and so it is not surprising that persons with this diagnosis would go on to disability. Persons diagnosed with carpal and cubital tunnel syndromes also demonstrated an elevated risk of disability (14.0%).

Several of the findings of natural history and disability predictors for specific diagnoses may be new, as this is the first study to examine the incidence of disability following hospitalization among various musculoskeletal diagnoses. The relative severities of disc degeneration, disc displacement, and chondromalacia in particular may result from the activity levels and physical demands that are often required of Army personnel. Further investigation into risk factors for these severe conditions may be warranted. Also, the severity of malunion or nonunion of fracture is not unexpected, given the fact that the diagnosis itself implies a complication. Disability associated with carpal tunnel syndrome appeared moderately severe, but not of greater severity than for any of the back conditions. Cheadle et al. (1994) found carpal tunnel syndrome to be associated with greater time lost from work than back/neck sprain, but did not assess the effect on physical disability as in my study.

5.1.2 Predictors of Disability

Results from the multivariate analyses indicate the presence of an independent association between several of the risk factors presented in the theoretical model (Chapter 1) and disability discharge, including age, pay grade/rank, length of service, job satisfaction, work stress, recurrent hospitalization, diagnostic category, smoking, physical demand, and education. Separate statistical models were produced for each functional group (e.g., back, knee, overuse, and other musculoskeletal conditions) for both sexes. Because of the dramatically fewer number of women in the study population (N=2246) relative to men (N=13,013), there may have been significantly less power to identify predictors of disability among women. This may explain why only five covariates were found to be significant for women while ten covariates were identified for men. However, another study also found far fewer significant predictors among women than among men (Pinsky et al., 1987), suggesting that these findings are consistent and valid.

Older age was an independent predictor of disability for men in all functional groups, but not for women in any group. Relative to subjects less than 21 years of age, the greatest risk was found in males aged 26-34 years for back (RH=13.1) and knee (RH=4.0) conditions. However, the oldest age group (35+ years) was at dramatically elevated risk for overuse conditions (RH=21.4) and other musculoskeletal conditions (RH=29.3). Pay grade/rank was also found to be an independent predictor among males, but not for females. For knee conditions, lowest ranking enlisted men (E1-E3) were at elevated risk (RH=6.3) relative to higher ranking enlisted men (E7-E9). Interestingly, enlisted men not of lowest rank but of E4-E6 rank were at greatest risk of discharge for back conditions (RH=1.9). Length of service was predictive of disability for both men and women. Men with 1-4 years of service were at highest risk for back (RH=2.8), overuse (RH=10.1), and other (RH=3.7) conditions, while men with 7-12 months were at highest risk for knee conditions (RH=3.6). Women with 6 or fewer months of service were at greatest risk for knee conditions (RH=6.3), while those with 1-4 years of service were at greatest risk for back conditions (RH=2.7), a finding consistent with that for men.

The results suggest an interesting association and potential conflict between the effects of age group, pay grade/rank, and length of service. Although these three covariates are highly correlated, older age, lower pay grade/rank, and intermediate length of service were associated with greater risk of disability. The finding of older age as a risk factor for disability is consistent with several other studies of musculoskeletal-related injury and disability (Berkowitz and Feuerstein, in press; MacKenzie et al., 1997; Liira et al., 1996; Badley and Ibanez, 1994; Cheadle et al., 1994; Hubert et al., 1993; Volinn et al., 1991; Leigh, 1985). The recent NIOSH review of musculoskeletal disorders and workplace factors suggests that "loss of tissue strength with age may increase the probability or severity of soft tissue damage from a given insult" (Bernard, 1997). The effect of older age has a slightly different interpretation in the dissertation than in the studies cited above; the outcome for those studies is the incidence of musculoskeletal-related injury or disability, whereas the outcome of the dissertation is the development of disability following the incidence of a condition. The fact that the study population was young (mean age=31 years) and there was relatively little spread in the distribution suggests that the effects of age were quite strong.

The apparent conflict between age, pay grade/rank, and length of service may exist because, although older persons may not heal as readily as younger persons, those in higher pay grades may not have as stringent physical demands associated with their jobs. Similarly, they may not need to return to as high a level of physical capacity as those in lower pay grades and with less time in service. Younger Army personnel, who tend to perform more physically demanding jobs, have also been found to have a higher risk of repeat injury (Schneider et al., 1998), possibly associated with higher levels of physical capacity required to perform their jobs. Intermediate length of service (7 months to 4 years) may reflect the process of disability boarding itself, which may require several months and may not accurately reflect the length of service for persons who experience a hospitalization early in their career.

My study identified high work stress and job dissatisfaction as risk factors for disability. Both men and women with knee conditions who were not satisfied with their jobs were at greatest risk (RH=1.7) relative to persons totally satisfied, although this finding was not statistically significant for women. Often experiencing work stress was only significant among males with overuse conditions (RH=2.8). These findings are consistent with the hypotheses that work stress and job satisfaction play a fundamental role in the development of musculoskeletal conditions (Bongers et al., 1993) and their resulting physical disability (Williams et al., 1998; Berkowitz and Feuerstein, in press). Alexander and Beck (1990) found that Army nurses who smoke experience significantly more job stress, job dissatisfaction, and less social support than nonsmokers or former smokers. Similarly, my study identified smoking to be correlated with greater job stress and job dissatisfaction (Chapter 4, Table 3). These results support the claim by Alexander and Beck that smoking cessation programs may benefit by also addressing issues of job stress, job satisfaction, and social support.

Experiencing a recurrent hospitalization for the same musculoskeletal diagnosis increased the risk of disability for men with both knee and other musculoskeletal conditions (RH=1.4). A recurrent hospitalization implies the presence of a complication or complex treatment for a more severe condition and serves as a surrogate for injury severity or a more complicated problem. That the magnitude of the risk was not greater or that this covariate was not significant for other conditions among both men and women was somewhat surprising. However, the requirement that the principal diagnosis in later hospitalizations exactly match the fourth or fifth digit ICD code may have resulted in a lack of sensitivity for this measure. Other research has suggested that the level of agreement for external cause of injury (E) coding is greater at the level of the third digit than at the fourth or fifth (Langlois et al., 1995). It is likely that an increased level of agreement would have been obtained by using the third digit level of the nature of injury (N) coding as well.

Men who were both heavy smokers (1+ pack/day) and light smokers (<1 pack/day) with knee conditions were at greater risk than nonsmokers (RH=1.7). However, smoking was not predictive of disability related to back conditions. The lack of evidence was unexpected given the significant literature relating smoking to the *incidence* of back conditions (Deyo and Bass, 1989; Tsai et al., 1992; Svensson et al., 1983; Finkelstein, 1995; O'Connor and Marlowe, 1993; Owen and Damron, 1984; Reynolds et al., 1994; Battié et al., 1989; Boshuizen et al., 1993; Frymoyer et al., 1980; Kelsey et al., 1984; Biering-Sørensen & Thomsen, 1986; Heliövarra et al., 1991; Saraste and Hultman, 1987; Dionne et al., 1995). Many of the same mechanisms that are suggested for increased incidence of back pain as a result of smoking (e.g., increased coughing raising abdominal and intradiscal pressures, decreased blood flow to discs, reduced mineral content of bones, chronic vasoconstriction, tissue deoxygenation, and increased muscle tone) were proposed to contribute to the development of disability as well (Chapter 1). However, the results did not support the hypothesis that smoking would affect disability among persons with back conditions. Perhaps the fact that this was a young cohort (mean age of 31 years) who tend to be involved in very physically demanding jobs (40% in the "very heavy" category) and maintain high levels of physical fitness contributed to greater relative stress on the knee than on the back or other body part. In the Army, the ramifications of a bad knee may be more severe than an injury to another body part, such as the back, in terms of being able to perform one's job task requirements and support one's unit. Alternatively, smoking may contribute to mechanisms that lead to back pain and back injury, but do not necessarily impair the healing mechanisms that would influence subsequent disability.

Although physical demand was found to be a significant predictor among men with back, knee, and overuse conditions, the direction of effect was not as expected. Those in jobs classified as "very heavy" were not at significantly higher risk than those with "light" jobs, as others have identified (Feuerstein et al., 1997; Cheadle et al., 1994; Makela et al., 1993). Perhaps the broad categorization scheme for physical demands resulted in some misclassification bias, thereby diluting the effect of this factor. It is unlikely that a subject would have been assigned to a less demanding job, although they may have received a temporary profile exempting them from specific activities that may exacerbate their condition. Unfortunately, this information was not available to include in the analysis.

Having less education was associated with greater risk among females, but not among males. Women with a high school education who experienced either a knee condition (RH=8.8) or overuse condition (RH=3.6) were at greater risk than women with college degrees. Similarly, other studies have found education to be the lone predictor among women, other than age, of good function (Pinsky et al., 1987). Many studies have identified education level as one of the strongest predictors of disability resulting from musculoskeletal conditions, including low back pain, lower extremity fracture, rheumatoid arthritis and good function (Dionne et al., 1995; Deyo and Tsui-Wu, 1987; Deyo and Diehl, 1988; MacKenzie et al., 1997; Badley and Ibanez, 1994; Makela et al., 1993; Hubert et al., 1993; Pinsky et al., 1987; Pincus and Callahan, 1985). Pincus and Callahan suggested education level to be "... a composite or surrogate variable, reflecting intrinsic abilities, income, access to and use of medical facilities, levels of personal responsibilities for health care, problem-solving experience, ..." and others. However, this study found a lower level of education to be an independent predictor of disability only among women with knee and overuse conditions and not for males of any diagnostic group. Education may have also reflected job factors, such as physical demands, that were not fully controlled for in the analysis. Perhaps the military environment, unique in its command-oriented structure, minimizes the effect of formal education on the development of physical disability. Also, the fact that even those with the least education had attained a high school diploma limits the variation in education level and may have muted its effect.

Among diagnostic categories, both women and men with a malunion or nonunion of fracture experienced significantly greater risk of disability than those with ganglion/cyst (RH=5.2 and 2.5, respectively). Within back-related diagnoses, disc degeneration was associated with greater risk than nonspecific back pain among men (RH=1.9), but not for women, possibly due to the small number of subjects. Disc displacement was associated with increased risk for both women (RH=2.4) and men (RH=1.5). Also, men with chondromalacia were at greater risk (RH=1.5) than those with meniscal injury. These results should be of interest to clinicians and may present an opportunity to examine the effect of treatment practices on the development of disability independent of the severity of the diagnosis.

5.1.3 Effect of Smoking on Disability

Results of Chapter 4 indicated an association between smoking level and disability discharge for all musculoskeletal diagnoses combined. Kaplan-Meier estimates illustrated distinct survival curves among different smoking levels, while log-rank tests for trend demonstrated dose-response relationships between smoking level and cumulative risk for disability discharge for all knee disorders (e.g., meniscal injury, cruciate ligament injury, collateral ligament injury, and chondromalacia), rotator cuff injury, and intervertebral disc displacement, but not for synovitis/tenosynovitis, carpal/cubital tunnel syndrome, ganglion/cyst, bunion/toe deformities, malunion/nonunion of fracture, nonspecific back pain, or intervertebral disc degeneration. Meniscal injuries in particular demonstrated a dramatic difference in risk between smokers (including both light and heavy) and nonsmokers..

When adjusting for stronger predictors of disability (e.g., age, diagnosis, pay grade) in multivariate Cox proportional hazards models, smoking was significantly associated with only meniscal injuries (former smokers had a 6% greater risk than nonsmokers (95% CI: 0.72, 1.54), light smokers had a 44% greater risk (95% CI: 1.07, 1.94), and heavy smokers had a 49% greater risk (95% CI: 1.06, 2.11)) and all diagnostic categories combined (heavy smokers had a 21% greater risk (95% CI: 1.04, 1.42)). When cases with meniscal injuries were removed from the group of all diagnostic categories, it was found that former smokers had a decreased risk (RH=0.92), light smokers had a slightly elevated risk (RH=1.04), and heavy smokers had the greatest risk (RH=1.16), though none of these results were statistically significant. Results from Cox models for carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, and chondromalacia suggest that smoking may affect disability following these diagnoses, though not at statistically significant levels.

Perhaps the most dramatic finding in this study was the association between smoking and the development of disability among persons with meniscal injuries. Among current smokers with meniscal injuries, 37.9% of disability discharges were attributable to smoking, or more than one of every three disability discharges. For the entire cohort (excluding former smokers), the attributable risk of disability due to smoking was 18.2% (95% CI: 9.1%, 27.3%), so nearly every fifth subject with a meniscal injury resulting in a disability discharge was related to smoking. These findings are very comparable to those of Rothenbacher et al. (1998).

I found no other literature to suggest that specific knee conditions would be affected by cigarette smoking. A few studies have identified an association between smoking and the broader definition of lower extremity injury (White, 1995; Reynolds et al., 1994; Jones et al., 1993), but nothing to indicate that the knee, or specifically, the meniscus, may be susceptible to the effects of smoking. It is expected that the impact of smoking would vary by diagnosis. Meniscal injuries represent perhaps the cleanest diagnostic group of injuries and are more likely to undergo hospitalization and a standardized treatment regimen (involving surgery) than other groups, such as back conditions. The relative uniformity associated with this condition and the fact that it was the most numerous (N=3653) may have contributed to its demonstrated association with smoking.

Since this finding persists after adjusting for various psychosocial and occupational factors, it suggests the presence of a physiological mechanism. This may involve the poor vascularization of the menisci, whereby the vascular structure only penetrates the peripheral 10-25% and at least the inner 75% of the menisci is avascular (Arnoczky and Warren, 1982) (Figure 1). Arnoczky and Warren suggest that "... isolated lesions in the avascular area would lack the blood supply necessary for an inflammatory and reparative response." Given that the menisci are provided with a limited blood supply in even the healthiest person, the effects of smoking (e.g., vasoconstriction, hypoxia, and immune suppression (Amoroso et al., 1996)), may further decrease the supply of nutrients to the damaged tissue and result in the interruption of the healing process and long-term dysfunction. Similar arguments have been espoused to explain the associations of smoking with wound healing, bone metabolism, low back pain (particularly related to a herniated disc), postoperative infection, and, in general, the healing of injured tissue with limited vascularization (Kwiatkowski et al., 1996). The most likely mechanism is nicotine's effect to constrict the microcirculation and reduce blood supply to the target organ, either indirectly through hormone release or directly through the production of catecholamines that promote peripheral vasoconstriction (Kwiatkowski et al., 1996).

The "J-shaped" dose-response curve suggests that former smokers are least likely to develop a disability resulting in discharge, even less so than nonsmokers. Although this trend was evident for many of the diagnoses, former smokers were never determined to be significantly at lower risk. Nonetheless, the cumulative survival curves (Chapter 4, Figure 1) indicated that former smokers may be protected, perhaps because they represent healthy survivors with a heartier constitution than others or, more likely, they have given up smoking as part of a series of behavioral changes (not controlled for in the model) that contribute to improved health and decreased likelihood of developing a disability. In either event, the difference in risk of disability discharge between heavy smokers and former smokers suggests that the effects of tobacco use prior to injury are not permanent and may, in fact, be reversible. These findings have considerable importance in developing recommendations to stop smoking.

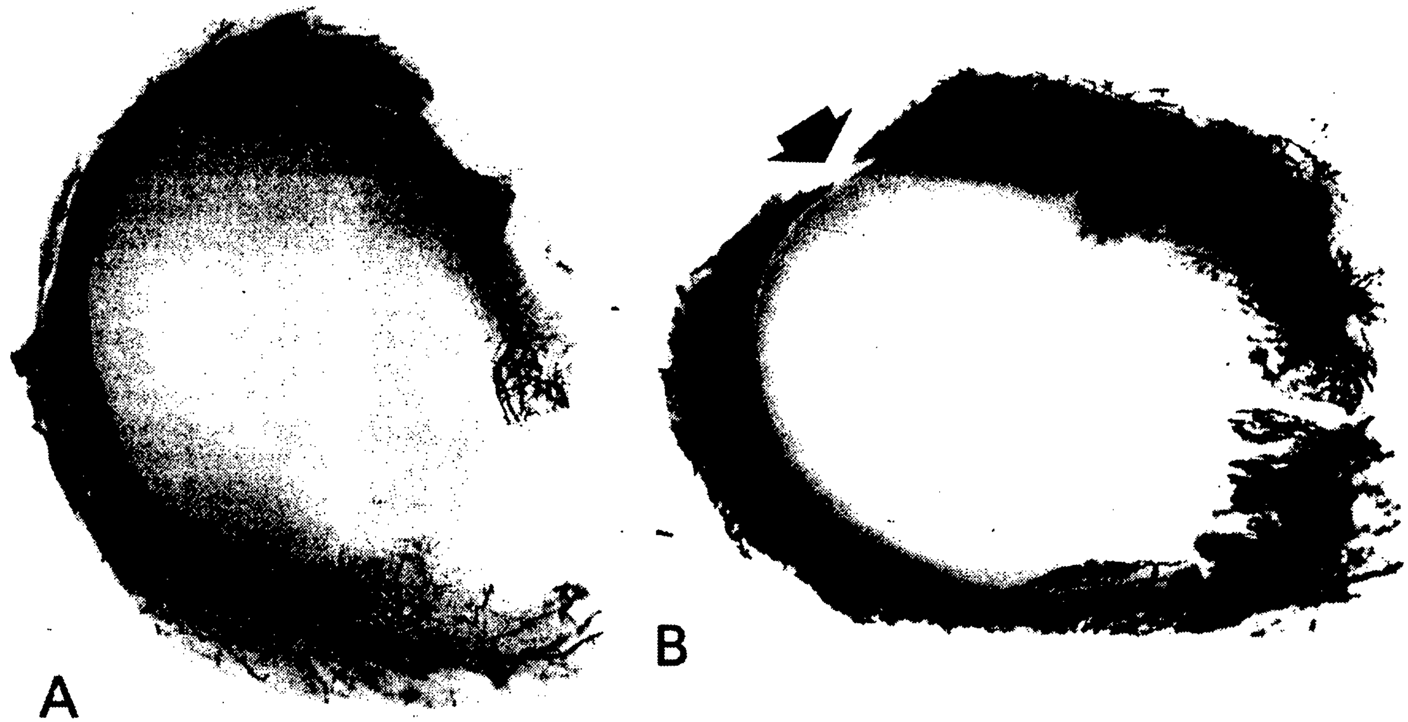

Figure 1. Superior aspect of the medial (A) and lateral (B) meniscus following vascular perfusion with india ink and tissue clearing using a modified Spalteholz technique. Note the vascularity at the periphery of the menisci as well as at the anterior and posterior horn attachments. The absence of peripheral vasculature at the posterior lateral corner of the lateral meniscus (arrow) represents the area of passage of the popliteal tendon.

Figure 1. Vascularization of the meniscus (Arnoczky and Warren, AJSM, 1982)

Among studies that investigate the effect of smoking in association with physical disability, the results of this study are largely consistent. In Leigh's prospective cohort study (1985), he found that cigarette smoking "...was strongly and positively associated with the probability of becoming disabled" after incurring an "accident or disease". In what is most likely the closest study to mine in terms of methodology and outcome (i.e., development of disability), Rothenbacher et al. (1998) produced similar measures of effect to those in Chapter 4 for both light smokers (RH=1.3) and heavy smokers (RH=1.6) when examining a cohort of construction workers for early retirement due to physical disability, though independent of the medical condition. Therefore, the relatively modest risks associated with smoking appear to be confirmed, as is the slight dose-response relationship, despite the overlapping confidence intervals of relative hazards at different levels of smoking. Also, Hubert and Fries (1994) found greater number of pack-years of cigarette smoking to be predictive of physical disability in their six year follow-up of an elder university cohort (mean age: 61 years). Other studies of physical disability among elderly populations have also identified smoking as a risk factor in population-based cohort studies (Guralnik and Kaplan, 1989; Pinsky et al., 1987; Pinsky et a l., 1985), although the outcomes used in those studies are more reflective of activities of daily living than ability to work. Also, German studies from the 1970s as referenced in Rothenbacher et al. (1998) identified smokers to be at increased risk for early retirement due to disability. Virtually all of these studies demonstrating a positive association between smoking and disability have utilized cohort designs and survival analysis techniques to provide results that are generally more robust than results from case-control or cross-sectional designs.

Among studies that did not identify a positive association, Makela et al. (1993) found that "smoking was not significantly associated with any measure of disability" in their cross-sectional study of determinants of disability in Finns with musculoskeletal disorders. Smoking dropped out of Berkowitz and Feuerstein's final model of predictors of long term disability from occupational low back pain in a case-control study of U.S. Army personnel (in press). This result is in agreement with my findings for back conditions, which did not demonstrate a significant association between smoking and disability (Chapter 4, Table 5).

5.2 Limitations and Strengths

A number of potential biases, limitations, and strengths associated with this study should be considered regarding the implications for future research and health policy.

5.2.1 Sources of bias

Sampling bias and generalizability: This study is intended to be generalizable to both Army personnel who experienced a musculoskeletal-related hospitalization and active duty personnel in general. Differences appear to be negligible in terms of sex, race/ethnicity, and education. However, the study cohort appears to be slightly older than both comparison groups and has a higher pay grade/rank as well. This may stem from a length of service bias resulting from the requirement that the subjects must have taken the Health Risk Appraisal to be included in the cohort. Since survey selection is not a random process, those with a greater length of service are more likely to have an opportunity to complete it, and those with a greater length of service tend to be older and have a higher pay grade/rank. Because age was associated with the development of disability (at least among men), this additional 2 to 3 years of age on average among the study cohort should be recognized when interpreting the results.

It is unclear how generalizable my findings are to the overall civilian population. Despite some differences in civilian and military work environments, this study population represented a wide variety of occupational groups, most of which had directly comparable tasks to those found in civilian jobs. Previous analysis of injury data showed that most of the injuries in the Army occurred during tasks equivalent to those in civilian jobs (Smith et al., in progress). Less than 5% of injuries occurred in combat or battle simulation conditions, with the remainder occurring in circumstances very similar to those experienced by the rest of the U.S. population. In addition, the effect of the job on the development of disability following an injury, rather than the incidence of a condition, is likely to be comparable between military and civilian occupations. Differences in criteria for hospitalization are addressed in the limitations section focusing on outpatient data.

My study did not include those personnel who were medically discharged for a musculoskeletal condition but were never hospitalized, so it is not generalizable to this group. Nor is it known what proportion of musculoskeletal-related disability discharges are never hospitalized. This group may have different risk factors for disability and represents an interesting policy issue that should be considered in future studies.

Simultaneous equation bias and reporting bias:

Because the behavioral data may have been obtained either before or after the initial hospitalization, there is the opportunity for simultaneous equation bias (Leigh, 1985). This suggests that the dependent variable (disability) and independent variable (smoking) may have a two-way causal relationship (i.e., smoking may increase the risk of disability, or disability may encourage one to smoke). In an effort to minimize this, the last personnel file update (which occur every six months) immediately prior to the initial hospitalization was used to provide information as accurate as possible. This is an important point as the subject may have changed their job after their hospitalization and I was not able to examine this influence on the development of disability. Similarly, if the HRA was taken on multiple occasions, the survey occurring closest to the hospitalization was used in data collection.

To assess whether smoking behavior was likely to change following hospitalization, a sub-analysis was performed. The kappa measure of agreement was assessed regarding smoking practice among those subjects who had completed the HRA prior to and following the initial musculoskeletal hospitalization (N=1452).

Results indicated very good agreement (kappa=0.74, 95% CI: 0.71, 0.77) between first and last HRAs regarding subjects' smoking status when classified as nonsmoker, former smoker, or current smoker. This result suggests that smoking practice remained stable over the course of several years (mean = 37 months, SD = 42 months) for this cohort and was not affected by their hospitalization.

A previous meta-analysis has indicated that self-reported tobacco use is accurate in most studies (Patrick et al., 1994). Furthermore, it is unlikely that any misclassification in self-reports of those with and those without musculoskeletal disorders would have been differential.

5.2.2 Limitations

Lack of validation for HRA: Although unpublished test-retest reliability evaluation of the Army HRA found all reliability coefficients equal to 0.7 or higher (U.S. Army Center for Health Promotion and Preventive Medicine, 1994), a potential limitation of the HRA data is the fact that it is self-reported behavior. However, the Behavioral Risk Factor Survey data indicate that the data obtained in such surveys is reliable and provides useful data (Frazier et al., 1992; Siegel et al., 1993). The version used by the Army has not been evaluated in its entirety for its validity and reliability as a predictive tool. Instead, "studies have concentrated on devising valid algorithms for risk estimates for specific topic areas within the HRA (e.g., coronary artery disease) and testing the predictive validity of those algorithms" (USACHPPM, 1994). However, most of the questions are very similar to those used by the Centers for

Disease Control and Prevention and other behavioral risk factor surveys.

Limited adjustment for heavy physical demands: Disability was not associated with very heavy physical demands in this study. This is a surprising finding given the literature indicating an association between physical demand and incidence of a musculoskeletal disorder or musculoskeletal-related disability (Bernard, 1997; Feuerstein et al., 1997; Liira et al, 1996; Cheadle et al., 1994; Makela et al., 1993). Four potential reasons may be responsible for this lack of association: 1) there truly is no association; 2) the lack of rating for officers or warrant officers limited the power to detect an association; 3) the classification scheme was not discriminating enough to detect a difference among physical demand levels; or 4) that physical demands influence the occurrence of musculoskeletal disorders but not whether the case goes on to disability. The most likely cause is the third, since the range of heaviness in "very heavy" jobs is very wide. In fact, 40% of all subjects were classified in jobs assigned to the "very heavy" category. In addition, there is evidence that heavy smokers are overrepresented among subjects in jobs defined as very heavy (Chapter 4, Table 3). This implies that the lack of discrimination using the physical demand variable may not have adequately controlled for the actual effect it played in the development of disability. Also, this measure is probably less predictive for higher ranking personnel, who tend to be more involved in supervisory tasks with fewer physical demands. These concerns suggest the need for a more sensitive measure of ergonomic risk associated with individual jobs.

<u>Lack of availability of outpatient data:</u> A limitation of this study results from the lack of computerized and available outpatient data for military patients during the study period. As a result, information on musculoskeletal disorders not serious enough to require hospitalization were not included in the data. In studies of Army soldiers by Tomlinson et al. (1987) and Reynolds et al. (1994), only 3% and 2.4%, respectively, of musculoskeletal injuries/conditions that were reported to sick call resulted in hospitalization. Without these cases, the "natural history" of the various diagnoses begins with hospitalization, rather than the more preferable outpatient visit, and the cases that can be followed are limited to those that are more severe. However, many of the initially hospitalized knee injuries were assigned a diagnosis indicating an old injury. This implies that many acute knee injuries that may not have required immediate hospitalization developed into chronic problems that eventually resulted in hospitalization and were captured in the cohort definition. This is more likely to be the case for persons with knee conditions than for persons with less definitive diagnoses or non-surgical treatment options, such as back conditions (Chapter 2, Table 1), especially since knee problems are more likely to result in some operative or investigative procedure prior to receiving a disability discharge. It is also important to recognize that "same day" surgery cases are included in hospitalization records for the Army, so that changes in treatment patterns should not affect their inclusion over time.

In the civilian community, the lack of outpatient data would be a considerable limitation. However, in the military this is likely to be less of a problem due to the lower threshold for hospitalization. Rates of injury hospitalizations for the services, particularly the Army, appear to be higher than those for civilian populations (Smith and Lincoln, 1998). However, military hospitalization rates may not be directly comparable to civilian rates (Smith et al., in progress). All service members have free health care and unlimited sick-leave so there is no potential barrier to hospitalization (e.g., incurring personal cost). In addition, some trainees, especially those living in group quarters, may have been hospitalized for relatively minor conditions such as stress fractures that may not require hospitalization in the civilian community.

Admission policies to military hospitals have recently been revised to become more similar to the model of private, for-profit hospitals (LTC P. Amoroso, personal communication, May 21, 1998). However, in the earlier parts of this study (1989-1994), hospitalization may have occurred simply because there was no one to care for individuals who could not participate in training during the day. Such instances reflect the unique environment and policies associated with the military.

<u>Lack of information on rehabilitation treatment/experience:</u> Exposure to a physical rehabilitation program can have a significant effect on outcome. Therefore, a study that addresses the development of physical disability would likely benefit by including parameters involving rehabilitation treatment. Such parameters might include the existence of physical and occupational therapy, the duration and frequency of therapy provided, and the modalities utilized during therapy. Unfortunately, this data was not available for inclusion in this study.

Lack of information on physical profiling: Physical profiles are assigned to Army personnel with temporary medical conditions to provide a measure of relative rest to spare the affected area. Personnel may be exempted from any activity that is determined by a physician to be "... either hazardous to service member's medical condition or causes 'undue' (i.e., inhumane) discomfort" (Department of the Army, 1995). Physical profiles are assigned to a soldier for up to 90 days at a time and can be extended for up to one year before requiring a Physical Evaluation Board to assess fitness for duty.

Physical profile data is maintained by Walter Reed Medical Center for all Army personnel. However, data are not available in a format that would enable it to be linked with other administrative databases. From a research perspective, the utility of physical profile data would be to provide a surrogate measure of severity for a condition.

5.2.3 Strengths

Study design: The use of a cohort study design rather than a case-control or cross-sectional design provided more credible evidence of a causal association between the independent factors and outcome of interest. The cohort design also enabled us to follow subjects over extensive lengths of time, potentially as long as nine years, and make use of all the person-time contributed by each subject to obtain more robust results. Also, by performing a retrospective study using existing administrative data, the cost of this effort was a small fraction of what would have been required to collect the same amount of data for a prospective study.

<u>Sample size:</u> The large sample size provided the power to investigate the effects of many covariates that are considered to be determinants of physical disability. When the study population was stratified by diagnostic category, all of the levels except perhaps intervertebral disc degeneration (N=130) included enough subjects to have the power to detect significant differences. However, when attempting to further stratify statistical models by sex, the small proportion of women (15%) may have contributed to fewer significant predictors obtained in models for women (5) than for men (10) in Chapter 3.

<u>Population-based sampling frame:</u> Rather than a clinic-based sampling frame that has often been used in other studies of disability (Lehmann et al., 1993; Lancourt and Kettelhut, 1992; Hasenbring et al., 1994; Coste et al., 1994; Williams et al; 1998; Deyo and Diehl, 1988), this study used a population-based sampling frame. Subjects included those from all demographic categories, from all occupational and geographic regions of the Army, and from an eight year range of hospital admission times. Therefore, the development of disability portrayed in this study should be highly representative of the experience among Army personnel hospitalized with a musculoskeletal disorder.

This population had the unusual benefit of having complete access to health care services. Despite the worldwide distribution of personnel, differences in the availability of health care services and geographic variations in treatment practices are minimal because of the constant rotation of military health care providers to different posts.

Range of study domains and characteristics included: The primary strength of this study was the ability to make use of a wide array of exposure data from a variety of high quality data sources. This enabled many of the non-medical factors that are considered to contribute to the development of disability to be included in the models and control for potential confounding. In particular, the inclusion of job satisfaction, work-related stress, physical demands of the job, and smoking practice were instrumental in developing a holistic approach towards the identification of potential risk factors.

Objective measure of disability: This study used an objective measure of disability, based essentially on whether the subject was fit for duty, where the duty was a function of the occupational specialty (Department of the Army, 1995). This determination was made by a Physical Evaluation Board consisting of 1-2 physicians and line officers using a standardized format. Because these determinations were made in the absence of pending litigation to receive benefits, there was a minimal degree of the antagonistic employee-employer relationship that is often evident with civilian worker compensation cases. Therefore, this research presents findings related to disability without the bias associated with attorney-involved litigation (Katz et al., 1997; Kasdan et al., 1996).

5.3 Directions for Future Research

The purpose of this study was to generate hypotheses that would explore factors relating to disability. One of the directions for future research involves refinement of the measurement and analytic techniques performed in this initial effort to verify the identification of risk factors in this population. Another direction for future research considers the primary findings as the basis for an intervention study.

5.3.1 Study Refinement

This study attempted to complete a number of broad objectives, among them: administratively coordinating the linkage of six administrative databases; investigating a wide array of common musculoskeletal diagnoses; investigating a wide array of covariates, and addressing a complex and multiply-determined outcome. This initial venture into musculoskeletal-related disability in the Army was completed using basic measurement and analytic techniques. Future research attempting to verify the findings from this study should consider the following suggestions to increase the sophistication of the methodology.

<u>Establish cohort at initial outpatient visit for specific diagnoses:</u> It would be much more informative in describing the natural history of musculoskeletal disorders if

subjects could be followed from their initial medical consultation, which would most likely be a sick-call or outpatient visit rather than hospitalization. The Department of Defense has initiated an effort to create a computerized service-wide database of outpatient visits, the Ambulatory Data System. Current efforts are underway to address data quality issues associated with this new surveillance tool (personal communication, LTC Paul Amoroso, USA, MC, August 1, 1998). This represents a tremendous opportunity for future research.

<u>Explore time-dependent variables:</u> Time-dependent variables represent another analytic tool that could be incorporated to improve the fit of the models. An example could involve a variable such as recurrent hospitalization, which could be represented in terms of time following initial hospitalization rather than the simple dichotomous variable that was used to represent the existence of a recurrent hospitalization. Other variables that may change over time, such as smoking practice, could be represented in this manner. This would offer a more accurate depiction of risk factors and exposure times over the course of potentially several years of follow-up.

<u>Verify changes in health behaviors among former smokers:</u> Although former smokers were not shown to be at significantly less risk than nonsmokers, there was a trend suggesting this phenomena. Efforts to improve health may involve behaviors related to dietary choice, exercise, weight control, and alcohol use in addition to smoking cessation (Tudor-Smith et al., 1998). It would be interesting to investigate what

additional changes in health behaviors typically are associated with smoking cessation and incorporate these into the model. For example, the aerobic exercise level could be assessed before and after smoking cessation.

Investigate more accurate measures of exposures: Disability was not associated with very heavy physical demands in this study. This surprising finding suggests the need for a more sensitive measure of ergonomic risk associated with individual jobs. One technique worth exploring would involve identifying the presence of specific ergonomic risk factors inherent to certain job tasks (e.g., heavy lifting, exposure to high vibratory forces, sustained awkward postures, etc.).

A measure of person-time (e.g., pack-years) would be desirable as a measurement of smoking and has been used in other studies of disability (Hubert and Fries, 1994). Unfortunately, the questions in the HRA that ask about smoking only request the duration of smoking among former smokers and does not include current smokers.

Incorporate the use of physical profile records: Inclusion of physical profile data would provide a surrogate measure of severity for a diagnosis. Profile data could be operationalized in terms of the total time on profile, time from initial medical visit to profile, or as rates of profiles associated with different diagnoses or occupations.

Incorporate the effects of surgical procedures and rehabilitation modalities involved in the medical care: A study that addresses the development of physical disability would likely benefit by including parameters involving both surgical procedures and rehabilitation treatment to evaluate their effectiveness when adjusting for potentially confounding variables. Ideally, surgical procedures would be recorded in terms of Current Procedural Terminology (CPT) codes, which are updated on an annual basis. This would be preferable to the ICD-9-CM procedure codes that are presently included in the hospitalization data. Unfortunately, because the ICD is not updated frequently, some of the procedure codes are outdated and no longer used. In addition, new procedures are not likely to be included and available for coding into patient records. Nevertheless, it would be interesting to examine the effect of specific treatment modalities on the development of disability for a given condition (e.g., surgery versus bed rest for nonspecific back pain).

The inclusion of parameters to reflect the rehabilitation experience would be helpful to improve the accuracy of the model as well. Parameters reflective of the rehabilitation experience might include type of treatment, the existence of physical and/or occupational therapy, the duration and frequency of therapy provided, and the modalities utilized during therapy.

5.3.2 Intervention Study

This study's principal finding was to identify smoking as an independent risk factor for the development of disability following a meniscal injury. This finding was suggested in a thorough literature review (Chapter 1) and includes a potential biologic mechanism that is considered to explain several other adverse health effects associated with smoking (Chapter 4). Therefore, such a finding is unlikely to be the result of chance.

Because this finding has not been recognized elsewhere, the results should be validated. Such validation, however, could be difficult because of the number of subjects and length of time necessary; validation may require considering smoking and physical disability within ongoing cohort studies. Because smoking has such a large attributable risk of disability (38% among smokers), confirmation of the finding would suggest that a smoking cessation intervention among Army personnel with meniscal injuries may help prevent the development of disability.

Recognizing smoking as a modifiable risk factor, an appropriate follow-up study would be a randomized clinical trial of smokers in the Army who are hospitalized with a meniscal injury. The concept is to introduce a smoking cessation intervention to a randomly selected number of patients that presently smoke cigarettes. Both those subjects exposed to the intervention and those who are not would be followed over time (approximately 5 years) to ascertain whether they develop a physical disability resulting in medical discharge from the Army. Results would provide an indication of whether a smoking cessation intervention would result in the decreased incidence of disability discharge from the Army, while adjusting for potential confounders. If positive outcomes are obtained from this prospective cohort study, the intervention could be extended to military and civilian populations on a larger scale.

Based on the five year cumulative risk of disability following hospitalization for a meniscal injury to be 11.5% overall (10% for nonsmokers and 17% for current smokers), preliminary calculations indicate that 1000 subjects would be required for a randomized clinical trial to yield a significance level of 0.05 and 80% power. Appropriate locations for such a trial might be posts such as Ft. Bragg, NC, and Ft. Hood, TX, where over 1300 persons were hospitalized for meniscal injuries between the years 1989 to 1995. Additional considerations might involve use of outpatient or sick call visits to increase sample size, inclusion of non-active duty personnel (e.g., families, civilian personnel working on base, retirees), and inclusion of other diagnoses suggested in this study to be associated with smoking (e.g., carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, chondromalacia). Successful smoking cessation would offer additional benefits to the individual beyond the reduced risk of developing disability (e.g., improved respiratory function, decreased cancer risk). Smoking cessation would also benefit the Army in improved readiness and reduce costs later incurred by the Department of Veterans Affairs and the U.S. taxpayer (Conway et al., 1993).

5.4 Policy Implications

The results from this study have potential ramifications to reduce the development of disability in the Army, particularly because musculoskeletal disorders lead the list of reasons for disability evaluations (Songer and LaPorte, 1996). This section discusses the findings in terms of opportunities for disability prevention (5.4.1), smoking policy in the Army (5.4.2), and the potential for physicians to affect smoking cessation among their patients (5.4.3).

5.4.1 Opportunities for Disability Prevention

Prevention of morbidity and mortality is typically classified into three levels: primary, secondary, and tertiary. Secondary prevention involves efforts intended to minimize the effects following an injury. "With such measures it is sometimes possible to either cure disease or slow its progression, prevent complications, limit disability, and reverse communicability of infectious diseases" (Mausner and Kramer, 1985). This study intended to identify risk factors for the development of disability with hopes of determining those that are modifiable or preventable. Among the significant predictors of disability found in this study, those that may be considered modifiable include job satisfaction, work stress, and smoking.

While other factors were also found to be significant predictors, many of them relate to characteristics that are either demographic (e.g., age, education level), occupational (e.g., pay grade, length of service, occupational category, physical demands), or clinical (e.g., diagnostic category, recurrent hospitalization) in nature. As such, opportunities to modify many of these factors may be more difficult in the Army environment. Indeed, while job satisfaction and work stress may be considered to be somewhat inherent to a job and relatively difficult to modify, changes in management style to include workers in safety and health related decisions (LaBar,

1989) and to consult workers regarding ergonomic modifications to their workstations (LaBar, 1994) have been credited with contributing to morale and lowering injury rates. Results from several studies indicate that an employee's perception of the workplace (Williams et al., 1998; Berkowitz and Feuerstein, in press; Bigos et al., 1992; Lancourt and Kettelhut, 1992) may affect the likelihood of disability following a work-related injury. Therefore, efforts to improve morale, with the byproducts or secondary effects of improving employees' perceptions, raising job satisfaction, and decreasing work stress may be considered opportunities to affect the development of disability, even within the confines of the Army environment.

The single significant behavioral predictor of disability was cigarette smoking. Smoking cessation represents perhaps one of the greatest individual-level interventions to reduce the risk of developing a disability in the Army, but undoubtedly one of the most challenging. To assess the potential for developing a smoking cessation program following injury, the following sections will examine smoking policy in the Army and the potential for physicians to affect smoking cessation.

5.4.2 Smoking Policy in the U.S. Army

With the finding of smoking as an important risk factor for disability among persons hospitalized with meniscal injuries, it is necessary to understand the military environment, policies, and historical backdrop regarding cigarette smoking if we are to consider a smoking-related intervention. This section briefly examines recent policy changes, smoking incidence and prevalence in the military, the current status of smoking cessation policy, and the need for effective program implementation.

Policy related to cigarette smoking in the U.S. Army has until recently been one of implicit encouragement. A number of subtle (and some more blatant) practices may have fostered a higher prevalence of smoking in the military than among civilians. Such practices include: price breaks on cigarettes available to military personnel (Ballweg and Li, 1989); the incorporation of the "smoke break" during training activities (Kroutil et al., 1994); the inclusion of cigarettes in soldiers' rations (Blake, 1985); and the promotion of an association between cigarettes and the military in commercial advertisements during World War II (ibid.).

Military service itself has been identified as a risk factor for cigarette smoking among both Americans (Klevens et al., 1995) and Norwegians (Schei and Sogaard, 1994). In their study of Norwegian army conscripts, Schei and Sogaard found that 56% of smokers increased smoking and 8% of nonsmokers began the practice after entering the military. Among American naval personnel deployed in Desert Storm, 29% of smokers increased smoking while 7% started smoking (Forgas et al., 1996). Among U.S. infantry recruits, Shahar and Carel (1991) identified a 50% increase in smoking prevalence during the first 14 weeks with 57% of former smokers resuming the habit. Similarly, Cronan et al. (1991) found that smoking among recruits jumped from 28% when they entered the Navy to 41% one year later; in addition, 54% of former smokers resumed smoking after one year. The same authors concluded that the military environment, in this case that of the Navy, encouraged smoking and that the Navy did not just attract smokers (Cronan and Conway, 1988). At the same time, it appears that many of the young recruits are already habitual smokers when they enter the service (Gunby, 1996), which may then be reinforced by the military environment. Efforts to help these individuals to stop smoking may be particularly difficult given the current environment in the military.

Military policy regarding smoking began to change in the 1980s as public attitudes first began to change regarding cigarette smoking and alcohol abuse (Gardner, 1991). Coinciding with this trend, Secretary of Defense Caspar Weinberger issued a memorandum in 1986 to establish an intensive anti-smoking campaign (Kroutil et al., 1994). The Army Health Promotion regulation was promulgated the following year, resulting in several dramatic policy changes related to smoking: building occupants were to be protected from second-hand smoke; smoking was prohibited during basic training; cigarette vending machines were removed from Army medical centers; and a tobacco screening was incorporated into regular dental check-ups (Gardner, 1991).

Since those initial efforts, problems have been identified with efforts to prevent or stop military personnel from smoking. Specifically, these include the effectiveness of tobacco cessation programs, the availability of over-the-counter cessation aids at exchange stores or medical treatment facilities, and incomplete establishment at all commands of a written policy regarding tobacco use (Conway et al., 1993). However, progress continued in 1994 as the Department of Defense banned the smoking of tobacco products in all of its military work facilities, including about 475 domestic and 100 international locations (Gunby, 1994). Additional efforts have targeted the removal of tobacco products from military base and ship exchange stores and commissaries, based on the belief that these sales undermine the antismoking campaign (ibid.). Resistance to this effort has been provided by some Congressional leaders, who contend that tobacco products are legal products and should be treated as such (ibid.).

The prevalence of smoking in the U.S. military has been dramatically reduced, from 51% in 1980 to 35% in 1992 (Bray et al., 1992). Significant declines in prevalence began in 1982 and have continued though the last worldwide survey in 1992 (ibid.). In addition to the policy changes that occurred during that time, the composition of the personnel changed as military needs demanded more technical-oriented personnel. The result was a personnel profile that was older, better educated, had more officers, and had more married persons in 1992 relative to 1980 (ibid.). Although all of these characteristics are associated with less substance abuse, standardization of the population's demographic characteristics in 1980 and 1992 did not account for the significant changes in smoking rates (Kroutil et al., 1994). These results imply that a combination of change in cultural norms regarding smoking acceptance (both in the military and society overall) and establishment of smoking cessation programs and policies resulted in the decline of smoking in the military (ibid.). Nonetheless, smoking rates in the military are far from the goal of 20% established by Healthy People 2000 (PHS, 1991) and 9% higher than that of the general population (Bushnell et al., 1997).

Efforts to quit smoking by Army personnel are substantial, with 52% of smokers attempting to quit within the past year, 22% of whom were successful (Bray et al., 1992). Those who unsuccessfully attempted to quit represent a group that may respond to cessation programs. Recent clinical trials of smoking cessation programs used with military populations have included the Vanderbilt University Medical Center (VUMC) behavior counseling program, the American Cancer Society (ACS) FreshStart program, and the Tripler Army Medical Center (TAMC) Tobacco Cessation Program (Bushnell et al., 1997; Faue et al., 1997). Among program compliers, the VUMC program initially enabled 80% to quit, although the quit rate was only 21% at 6-month follow-up; the ACS program was effective with 58% by the end of the program, but only 19% at 6-month follow-up (Bushnell et al., 1997). The TAMC program's 1-year sustained abstinence rate of 27% was encouraging relative to the 20% obtained in smoking cessation trials that used the combination of nicotine replacement and behavioral therapy (Faue et al., 1997; Norregaard et al., 1993).

Bushnell et al. summarized the major reasons for successful smoking cessation in the military to include class attendance, free nicotine-replacement therapy, higher education level, reduced stress, older age, and advice from physicians. Reasons associated with failure are increased stress, nicotine-withdrawal symptoms, deployment or potential deployment, and change in assignment as well as reasons commonly associated with failing to quit (e.g., weight gain, depression, boredom, youth, separation from family). Lastly, the authors recommend "that a brief, tailored intervention program be used for military personnel who smoke, with the addition of nicotine-replacement therapy and strong organizational support." The need for "strong organizational support" speaks to the importance of efforts to reinforce attempts to alter the accepting and condoning of smoking that permeated the military so strongly. Programmatically, this may involve active promotion of cessation activities and enforcement of no smoking statutes, efforts to make it more difficult to smoke by changing the social environment.

5.4.3 The Physician's Role in Smoking Cessation

The communication of a diagnosis, such as cancer, provides a teachable moment in which a physician can counsel or teach the patient (Schilling et al, 1997). This "teachable moment" at the presentation of a diagnosis of meniscal injury could include the suggestion of smoking cessation as a means of reducing the likelihood of the development of disability and subsequent discharge from the Army. Discharge is likely to be considered an unattractive prospect associated with the potential loss of benefits. In addition, the prospect of attempting to obtain employment in the private sector with a significant physical impairment can be formidable, particularly to personnel with limited skills that may be transferrable to the civilian workforce.

A discussion of smoking cessation may be indicated for patients with a diagnosis of meniscal injury in the same way that it is indicated for patients diagnosed with coronary artery disease, stroke, chronic obstructive pulmonary disease, or other condition exacerbated by smoking. Smoking cessation is significantly more likely to occur when even brief physician advice is administered (Fiore et al., 1996) and may be particularly well-received by a patient if they are in the *contemplation* or *preparation* stage of Prochaska and DiClemente's model of behavior change (1992). Winslow et al. (1996) suggest that in order to eliminate or reduce risk factors through lifestyle modification, "physicians should use an approach similar to that followed in other treatment plans: First, help the patient understand the value of the therapy; second, discuss the way in which treatment will evolve and set appropriate goals; third, follow-up by monitoring and encouraging the patient's progress and identifying any barriers or adverse effects."

There is an apparent need for skill development among health care providers in tobacco cessation counseling techniques. Conway et al. (1996) found that 67% to 75% of U.S. Navy health care providers engaged in only four of eleven recommended practices with tobacco-using patients. The authors recommend efforts to "train all military health care providers ... to use the National Cancer Institute's 'Four A's' approach for patient tobacco cessation," refering to the brief "Ask, Advise, Assist, Arrange" method (Glynn and Manley, 1990). The inclusion of all health care providers (e.g., physician assistants, nurse practitioners, nurses, therapists, etc.) In cessation counseling techniques may serve to increase the frequency and quality of smoking cessation encounters while reinforcing the message and concern for the patient. Successful programs will require that health care providers learn methods of delivering advice succinctly, particularly if military health care providers share the same limited training as many U.S. civilian physicians (Frankowski et al., 1993).

5.5 Conclusion

This study successfully demonstrated that it is possible to link large existing administrative databases for the epidemiological study of injury and disability. This population-based, retrospective cohort study described the development of disability following hospitalization for common musculoskeletal disorders, identified risk factors for disability within functional groupings of conditions, and addressed the role of smoking on the development of disability for each diagnostic category.

Results indicated back-related diagnoses to be the most severe in terms of cumulative disability risk at 6 months, 12 months, and 5 years. Causes of disability are multiply determined with risk factors that include older age, less education, lower pay grade/rank, intermediate length of service, recurrent hospitalization, heavy cigarette smoking, lower job satisfaction, and greater work stress. Smoking was found to be an independent risk factor for disability among meniscal injuries and may also affect persons with carpal tunnel syndrome, rotator cuff injury, collateral ligament injury, and chondromalacia. Among current smokers with meniscal injuries, 38% of disability discharges were attributable to smoking, while the attributable risk of disability due to smoking among current smokers and nonsmokers was 18%.

A sound physiological mechanism to explain why smoking affects the development of disability for meniscal injuries relates to its potential effects on the vascularity of the meniscus. Because the meniscus has limited vascularization that only penetrates the peripheral 10-25%, smoking may further reduce the supply of nutrients to the damaged tissue, thereby interfering with the healing process. This study represents the initial finding of an association between smoking and the development of disability for meniscal injuries and, therefore, requires validation. If the finding is confirmed, it suggests that a smoking cessation intervention among Army personnel who injure their menisci may serve as an important means to prevent the development of disability.

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ANDREW E. LINCOLN, M.S., Sc.D.

PII Redacted

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OBJECTIVE: To prevent injury and disability among workers by applying principles of injury control, epidemiology, ergonomics, and rehabilitation.

EDUCATION:

May 1989

Virginia Polytechnic Institute and State University-Blacksburg, VA
Bachelor of Science in Engineering Science and Mechanics (B.S.)
- Biomedical Engineering Option
- Marshall Hahn Engineering Scholarship

November 1990

Louisiana Tech University - Ruston, Louisiana
Master of Science in Biomedical Engineering (M.S.)
- Concentration in Rehabilitation Engineering
- Louisiana Board of Regents Graduate Fellow

September 1998

Johns Hopkins School of Public Health - Baltimore, Maryland
Doctor of Science (Sc.D.) in Occupational Injury Epidemiology
- Received full scholarship from National Institute for Occupational Safety and Health Training Grant
- William Haddon, Jr., Memorial Fellow in Injury Control, 1997-98

CLINICAL EXPERIENCE:

1990 - 1996

National Rehabilitation Hospital - Washington, DC
Senior Clinical Rehabilitation Engineer
- Directed and supervised clinical activities of the Assistive Technology/ Rehabilitation Engineering Program
- Coordinated and performed multidisciplinary clinics with other allied health professionals in the areas of Worksite Accommodation, Ergonomics, Augmentative and Alternative Communication, Environmental Control, Home Modification, Seating and Mobility, Computer Access, and Adaptive Driving

- Presented lectures for research symposiums, graduate-level courses, training seminars, and hospital staff
- Performed epidemiologic study of injuries to nurses at The National Institutes of Health Clinical Center

RESEARCH EXPERIENCE:

1998 - present

Georgetown University Medical Center - Washington, DC
Department of Psychiatry
***Research Consultant*:** Maximizing Outcomes in the Federal Workers' Compensation System Through Integrated Case Management study

- supported by The Robert Wood Johnson Foundation
- develop ergonomic training materials for case managers, provide training, and provide technical assistance for worksite accommodations for disabled workers with upper extremity disorders

1998 - present

Johns Hopkins School of Public Health - Baltimore, Maryland
Health Policy and Management Department
Center for Injury Research & Policy
Research Consultant: Cochrane Collaboration for Occupational Health

- Head the Center's effort to review the effectiveness of various return-to-work rehabilitation programs

1996 - present

Johns Hopkins School of Public Health - Baltimore, Maryland
Health Policy and Management Department
Center for Injury Research & Policy
Project Manager: Ergonomic Injuries in Motor Vehicle Manufacturing Parts Depots study

- UAW-Chrysler sponsored research
- Coordinate communications between the UAW-Chrysler, University of Michigan, and Johns Hopkins University
- Manage and analyze epidemiologic data for the study
- Wrote report detailing the epidemiology of injuries

1996 - present

Johns Hopkins School of Public Health - Baltimore, Maryland
Health Policy and Management Department
Center for Injury Research & Policy
Research Assistant: Women in the Military study

- Perform epidemiologic analysis of musculoskeletal injuries using military administrative databases
- Assist in the development of proposals, writing of papers and abstracts, analysis of results, and presentation of studies

1996 - present	Johns Hopkins School of Public Health - Baltimore, Maryland Health Policy and Management Department Center for Injury Research & Policy ***Project Sponsor:*** Johns Hopkins Mechanical Engineering Senior Design Projects • Automatic page turner for use by a high level quadriplegic • Vehicle modifications to protect EMTs during ambulance crashes • Interventions to reduce school bus-related injuries among children
1997 - present	Johns Hopkins School of Public Health - Baltimore, Maryland Population Dynamics Department ***Research Assistant:*** Childhood Injuries in the Home study • Perform epidemiologic analysis of state hospital discharge data for pediatric injuries
1997 - present	Johns Hopkins School of Medicine - Baltimore, Maryland Orthopaedics Department ***Research Assistant:*** Pediatric Femur Fracture study • Perform epidemiologic analysis of state hospital discharge data for pediatric femur fractures
1997 - present	Johns Hopkins School of Public Health - Baltimore, Maryland Center for Injury Research & Policy ***Teaching Assistant:*** various courses, including • Issues in Injury Control, Instructors: Susan Baker, Stephen Teret • Epidemiology of Injuries, Instructors: Gordon Smith, James Weeks • Occupational Injury and Safety Science, Instructor: Gordon Smith • The Johns Hopkins Center for Injury Research and Prevention Summer Institute, Instructors: Ellen MacKenzie, Carolyn Fowler
1995- present	Uniformed Services University of the Health Sciences - Bethesda, Maryland Medical/Clinical Psychology and Preventive Medicine ***Research Consultant:*** Occupational musculoskeletal disorders • Assist in the development of proposals, literature reviews, analysis of results, and presentation of studies
PROFESSIONAL MEMBERSHIPS:	American Public Health Association Human Factors and Ergonomics Society

PUBLICATIONS/MANUSCRIPTS:

1. Feuerstein M, Armstrong T, Hickey P, **Lincoln AE:** Keyboard force, fatigue and pain in symptomatic word processors. *Journal of Occupational and Environmental Medicine* 1997;39(12):1144-1153.

2. Smith GS, **Lincoln AE:** A response to the Home Depot study of backbelt effectiveness (letter to editor). *International Journal of Occupational and Environmental Health.* 1997;3(3):237-238.

3. Feuerstein M, Burrell L, Miller V, **Lincoln AE,** Berger R, Huang G: Clinical Management of Carpal Tunnel Syndrome: A 12 Year Review of Outcome Studies. In press: *American Journal of Industrial Medicine.*

4. Wong T, **Lincoln AE,** Baker S: Epidemiology of Ocular Injury in a Major U.S. Automobile Company. In press: *Eye.*

5. **Lincoln AE**, Baker SP, and Amoroso PJ. The Use of Existing Military Administrative and Health Databases for Injury Research. In press: *American Journal of Preventive Medicine.*

6. Hinton RY, **Lincoln AE,** Crockett MM, Sonseller P, Smith GS. Pediatric Femoral Shaft Fractures: Incidence, Mechanisms, and Sociodemographic Risk Factors. In press: *Journal of Bone and Joint Surgery.*

MANUSCRIPTS IN PROGRESS:

1. **Lincoln AE**, Smith GS, Amoroso PJ, and Hinton RY. The Association Between Musculoskeletal Conditions, Disability, and Smoking: A Review of the Literature.

2. **Lincoln AE**, Smith GS, Amoroso PJ, and Bell NS. The Natural History and Risk Factors of Musculoskeletal Conditions Resulting in Disability Among U.S. Army Personnel.

3. Smith GS, **Lincoln AE**, Hinton RY, and Amoroso PJ. The epidemiology of musculoskeletal conditions in the U.S. Army, 1989-1994.

4. Lauder TD, Baker SP, Smith GS, and **Lincoln AE**: Sports and Physical Training Injuries in an Active Duty Army Population. *American Journal of Preventive Medicine.* Submitted.

5. Levick N, **Lincoln AE** , Mize B, Gupta P, and Saupe A. The Safety Of Ambulance Transport For Emergency Medical Technicians.

6. Smith GS, Wong TY, **Lincoln AE,** Vinger P. Epidemiology of Ocular Injury in the U.S. Army from 1985 to 1994.

7. **Lincoln AE**, Smith GS, Amoroso PJ, and Bell NS. The Effect of Cigarette Smoking on Musculoskeletal-Related Disability.

REPORTS:

1. **Lincoln AE**, Baker SP. The epidemiology of overexertion injuries at UAW/Chrysler Parts Depots and Distribution Centers, January 1991-December 1996. Presented to the UAW-Chrysler Health and Safety Scientific Advisory Committee. June 1997.

2. **Lincoln AE**, Neway B, Tepper S. Injuries to nurses at The National Institutes of Health Clinical Center. Presented to NIH Nursing Administration. 1994.

ABSTRACTS/PRESENTATIONS/LECTURES:

1. **Lincoln AE**: Musculoskeletal Disorders and Worksite Accommodation. (Presented at the Johns Hopkins NIOSH Educational Resource Center's Advancements in Musculoskeletal Disorders Seminar, Baltimore, MD, June 1996-1998).

2. **Lincoln AE**, Smith GS, Amoroso PJ, Bell NS: The Natural History of Musculoskeletal Conditions Resulting in Disability Among United States Army Personnel. (Presented at the New England Occupational Injury Research Group Spring 1998 Symposium, Hopkinton, MA, May 1998).

3. **Lincoln AE**: The Influence of Smoking on Disability Following Hospitalization for Musculoskeletal Disorders. (Presented to the Johns Hopkins Center for Injury Research and Policy, Baltimore, MD, Dec. 1997).

4. **Lincoln AE**, Baker SP: Injuries in UAW-Chrysler Auto Manufacturing (1989-92): An Ergonomic Landscape. (Invited presentation at the First Annual UAW-Chrysler Ergonomics Conference, Detroit, MI, Nov. 1997).

5. **Lincoln AE**, Wong TY, Baker SP: Epidemiology of Ocular Injury in a Major U.S. Automobile Company. (abstract--presented at National Occupational Injury Research Symposium '97, Morgantown, WV, Oct. 1997).

6. **Lincoln AE**, Baker SP, Smith GS: The Effect of Workers' Compensation Likelihood on the Reporting of Cumulative Trauma Disorders. (abstract--presented at National Occupational Injury Research Symposium '97, Morgantown, WV, Oct. 1997).

7. Smith GS, **Lincoln AE**, Baker SP, Forney CK: Use of Surveillance Databases for Analytic Research: Hospital Databases in the Army. (abstract--presented at National Occupational Injury Research Symposium '97, Morgantown, WV, Oct. 1997).

8. Smith GS, **Lincoln AE**: Hospitalization for Musculoskeletal Conditions: Comparisons Among Army and Civilians by Gender. (abstract--presented at Fourth World Conference on Injury Prevention and Control, Amsterdam, The Netherlands, May, 1998).

9. **Lincoln AE**, Perr A, McGovern T. Pressure Distribution on Custom Contoured Wheelchair Cushions Compared to Other Seat Cushions. Proceedings of the Ninth International Seating Symposium.

10. Perr A, **Lincoln AE**, McGovern T. Pressure distribution on custom contoured wheelchair cushions utilizing the electronic shape sensor. Proceedings of the RESNA International '92 Conference.

11. **Lincoln AE**, Keller RD, Lavery LA, Pezzini L, Burkhalter D. Accommodations for a therapeutic kayaking program. Proceedings of the RESNA International '92 Conference.

REVIEWER: Reviewed abstracts submitted to the National Occupational Injury Research Symposium '97 and the American Public Health Association 126th Annual Meeting and Exposition (Injury Control and Emergency Health Services section)

COMPUTER SKILLS: SPSS, Stata, EpiMap, Visio, WordPerfect, Word, PowerPoint, Excel, Paradox, Access, Stat/Transfer